A

TEXT BOOK

OF

PRODUCTION ENGINEERING

Dr. P. C. Pandey
Assc. Prof. Mech. Engg.

C. K. Singh
Reader in Mech. Engg.

University of Roorkee
Roorkee

&

Prof. Balbir Singh (Late)
Punjab Engg. College
Chandigarh

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compressed to such an extent that the deformed metal starts sliding along the face and the magnitude of compression force reaches the

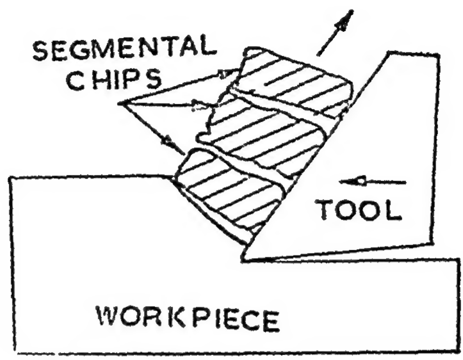


Fig. 2.04 Discontinuous Chips (Type I)

fracture limit of the metal. The factors responsible for the development of discontinuous chips are :

1. Brittle and nonductile metals ;(Cast Iron, Brass castings, Berellium, Titanium etc.),
2. Low cutting speed and
3. Small rake angle in the cutting tool.

Since the chips are smaller, their handling becomes easier and they may be easily disposed off. Shorter chips will further impart good finish on the work surface since they do not interfere with the work surface.

Continuous Chips : Such chips are in the form of long coils having the same thickness throughout. The chips are produced due to the plastic deformation of the metal without rupture. Continuous chip without built-up edge is difficult to obt-

ain at normal cutting speeds. However, they can be had at very high speeds when the surface finish, and tool life improves and the power

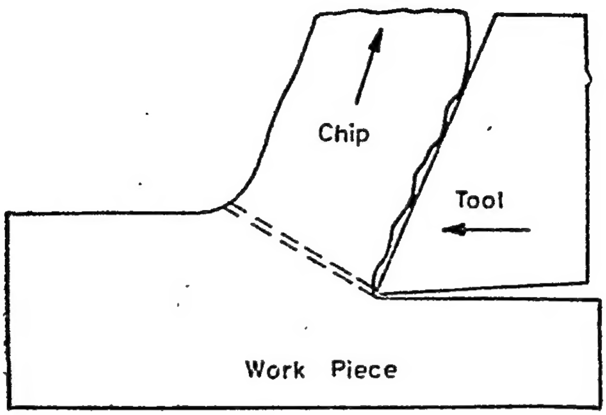


Fig. 2.05 Continuous Chips (Type II)

consumption reduces. The factors responsible for continuous chips are :

1. Ductile material,
2. High cutting speed,
3. Large rake angle,
4. Sharp cutting edge,
5. Efficient cutting fluids, and
6. Tool material giving low friction between tool face and chips.

Continuous Chips with B.U.E. Such chips also appear in the form of long coil but they are not as smooth a type II (fig. 2.06). On closely observing the cutting edge of the tool a small lump of metal welded to the chip tool contact area can be located at zone 1. This kind of welding is due to high pressure at the cutting edge. The lump of metal is known as **built-up edge.**

The built-up edge grows gradually at the cutting edge. When its growth is sufficiently large, it collapses, A part of it escapes with the chips in the form of very thin flakes (2) adhering underneath the escaping chips. Another part (3) of it gets embeded on the finished

surface while the remaining part remains welded at zone 1. This part again grows up and collapses as described above. The hardness of this mass has been estimated 2 to 3 times higher than that of material being machined. This is the reason why the cutting edge remains active even when it is covered with built-up edge.

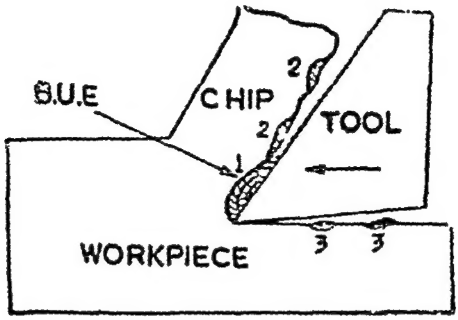


Fig. 2.06 Continuous Chip with Built Up Edge (Type III)

The only point in favour of BUE is that it protects the cutting edge from wear due to moving chips and the action of heat. This brings about an increase in tool life. Otherwise, presence of BUE means poor surface finish because a portion of it is pressed on the finished surface. Therefore, it is desirable to keep the size of BUE as small as possible for best possible speed. Factors, responsible for BUE are ;

1. Ductile material
2. Coarse feed
3. Small rake angle
4. Low cutting speed
5. Dull cutting edge
6. Insufficient cutting fluid
7. High friction at the chip-tool interface.

The BUE may cause the failure of the tool by cratering at the tool face and abrasion on the tool flank due to the hard fragments of BUE escaping with the workpiece.

Table I

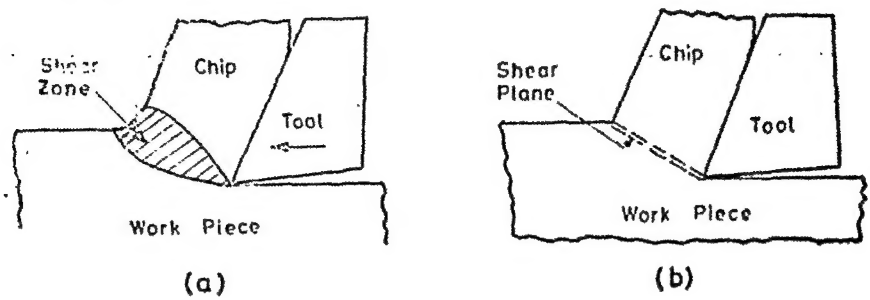
Factors responsible for the formation of different types of chips.

Factors	Types of Chips: Discontinuous	Types of Chips: Continuous	Continuous with B.U.E.
Material	Brittle & Non-Ductile	Ductile	Ductile
Cutting speed	Lower	Higher	Low
Tool Geometry (*i.e.* Rake)	Smaller	Larger	—
Cutting Fluid	—	Efficient	Poor
Friction	—	Lower	High
Feed	—	—	Coarse
Cutting Edge	—	Sharp	Dull

2·05 BASIC MECHANISM OF CHIP FORMATION

Irrespective of the basic nature of the chips obtained during machining of metal, the main factor governing the formation of chips is the plastic deformation of the metal by shear process. According to earlier investigators (Merchant etc,) the deformation of metal occurs along a plane just ahead of the tool and running upto free work surface (fig. 2.07 *b*), without any plastic flow on either side of the plane. After passing out of the shear plane the deformed metal slides along the tool face due to velocity of the cutting tool. At a later stage other investigators (Oxley, Hitomi and Okushima etc.) have suggested zone formation instead of a plane

at the transition zone based upon several photomicrographs fig. 2.07 (*a*). The size of the shear zone is thick if metal is machined



Fig, 2.07 Shear Zone and Shear Plane in Chip Formation.

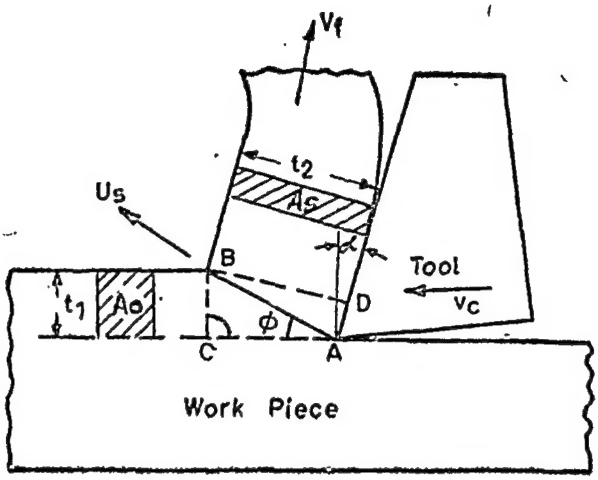
at low cutting speeds and thin if metal is machined at high cutting speeds. Even a few investigators have proposed two shearing zones instead of one. The additional zone has been described at chip tool interface. With this information it has been possible to explain the formation of built-up-edge.

The width of the deformed chip has no relation with the width of the undeformed chip. When the cutting velocity changes width and thickness both, vary to a large extent. It has been reported by Loladze that the chip width b_2 and chip thickness t_2 do not correspond to the initial values b_1 and t_1.

2·06 GEOMETRY OF CHIP FORMATION

The formation of all the basic types of chips have been described with the help of geometrical models derived from actual photomicrographs. The simplest geometrical representation is that of type-II chip. This model conveys pratically all the informations which suit the models of other types of chips to a very great extent. This is illustrated in fig. 2.08.

The tool moves with a velocity V_c against the work and thereby, shears the metal along the shear plane AB. The outcoming



Frg. 2.08 Geometry of chip formation.

chip of thickness t_2 experiences two velocity components V_f and V_s along the tool face and shear plane, respectively. The depth of cut is t_1 which is actually the feed in the machining operation. From the above configuration it is possible to compute the value of shear angle (ϕ) in terms of measurable parameters t_1, t_2, and α.

From the right angle $\triangle$ ABC.

$$AB = \frac{t_1}{\sin \phi}$$

Again, from the right angled triangle ABD

$$AB = \frac{t_2}{\sin(90 - \phi + \alpha)} = \frac{t_2}{\cos(\phi - \alpha)}$$

$$\therefore \quad \frac{t_1}{\sin \phi} = \frac{t_2}{\cos(\phi - \alpha)}$$

or $\dfrac{t_1}{t_2} = \dfrac{\sin\phi}{\cos\phi\cos\alpha + \sin\phi\sin\alpha}$

Let $r_t = \dfrac{t_1}{t_2}$, where r_t is termed chipthickness coefficient

or $\dfrac{1}{r_t}$ is termed chip reduction coefficient and denoted by k.

Thus, $\dfrac{r_t\cos\phi\cos\alpha}{\sin\phi} + \dfrac{r_t\sin\phi\sin\alpha}{\sin\phi} = 1$

or $r_t\cos\alpha = (1 - r_t\sin\alpha)\tan\phi$

$$\therefore\ \tan\phi = \frac{r_t\cos\alpha}{1 - r_t\sin\alpha} \qquad \text{......2·01}$$

The knowledge of the parameters t_1, t_2, ϕ and α can now fully define the model of continuous chips.

The chip thickness ratio can also be expressed in a different way. Let l_2 be the length of the cut chip which had a length l_1 before cutting As the volume remains constant, it may be written,

$$l_2 \times t_2 \times b_2 = l_1 \times t_1 \times b_1 \qquad \text{......2.02}$$

where b_1 is width of cut and b_2 is the width of chip. When there is no side flow of metal then $b_1 = b_2$.

$$\therefore\ l_2 \times t_2 = l_1 \times t_1$$

$$\text{or} \quad \frac{l_2}{l_1} = \frac{t_1}{t_2} = r_t \qquad \text{... 2.03}$$

In case side flow is considered then chip thickness ratio is to be multiplied by λ, side flow factor, to obtain the length ratio, when $\lambda = \dfrac{b_1}{b_2}$.

2.07 FORCES ON THE CHIP

It is convenient to understand the forces acting on the tool-work-chip system in orthogonal cutting.

The relationships amongst the various forces (Fig. 2.09) have been worked out by Merchant with a large number of assumptions :

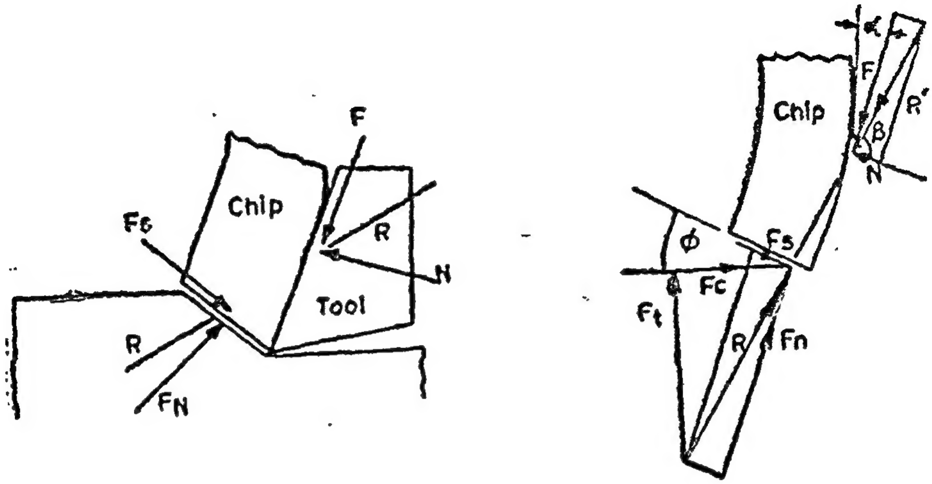


Fig. 2.09 Force components acting on the Chip.

1. The cutting edge of the tool is sharp and it does not make any flank contact with the workpiece.
2. Only continuous chip without built-up edge is produced.
3. The chip does not flow to either side.
4. The cutting velocity remains constant.
5. The chip behaves as a free body in stable equillibrium under the action of two equal, opposite and almost collinear resultant forces.
6. The inertia force of the chip is entirely neglected.

Thus, the following two vector equations can be written down :

$$\vec{R'}=\vec{F}+\vec{N}$$

$$\vec{R}=\vec{F_s}+\vec{F_n}=\vec{F_c}+\vec{F_t}$$

Merchant suggested a compact and convenient way of representing the forces inside a circle. The tool and reaction forces are plotted as concentrated at the tool point instead of their actual points of application along the tool face and shear plane. It is thus possible to trace a circle having the diameter equal to R or F

which passes through tool point (fig. 2.10). In this diagram the quantities which can be measured are F_c and F_t. (by a suitable tool dynamometer) t_1, t_2 and ϕ (by calculation). Therefore, other quantities are expressed in terms of known parameters only.

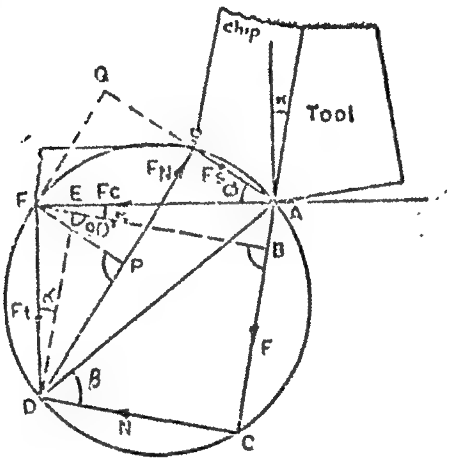


Fig. 2.10 Force Diagram (Due to Merchant)

As the chip slides over the tool face under pressure therefore, the kinetic coefficient of friction may be expressed as

$$\mu = \frac{F}{N} = \tan \beta \qquad \ldots \quad 2.04$$

Other force relationships

1. $F = F_t \cos \alpha + F_c \sin \alpha$ 2.05

$N = F_c \cos \alpha - F_t \sin \alpha$ 2.06

As $F = AB + BC$

$= AB + DE$

$= F_t \cos \alpha + F_c \sin \alpha$

$N = FB - FE$

$= F_c \cos \alpha - F_t \sin \pi$

2. $F_s = F_c \cos \phi - F_t \sin \phi$ 2.07

$F_N = F_t \cos \phi + F_c \sin \phi$ 2.08

As $F_s = AQ - QR$

$= AQ - FP$

$= F_c \cos \phi - F_t \sin \phi$

$$F_N = DR = DP + PR$$
$$= DP + FQ$$
$$= F_t \cos\phi + F_c \sin\phi$$

3. $$F_c = AD\cos(\beta-\alpha)$$
$$= \cos(\beta-\alpha)$$
$$F_s = R\cos(\phi+\beta-\alpha)$$
$$\frac{F_c}{F_s} = \frac{\cos(\beta-\alpha)}{\cos(\phi+\beta-\alpha)}$$

or $$F_c = F_s \times \frac{\cos(\beta-\alpha)}{\cos(\phi+\beta-\alpha)} \quad \ldots\ 2.09$$

4. $$\frac{F}{N} = \frac{F_c\sin\alpha + F_t\cos\alpha}{F_c\cos\alpha - F_t\sin\alpha}$$
$$= \frac{F_t + F_c\tan\alpha}{F_c - F_t\tan\alpha}$$

Also $$\frac{F}{N} = \tan\beta = \mu \quad \ldots\ 2.10$$

and $$\frac{F_t}{F_c} = \tan(\beta-\alpha) \quad \ldots\ 2.11$$

2.08 VELOCITY RELATIONSHIPS

Three velocities come into existence when the tool cuts the the metal. The velocity of tool relative to work is known as cutting velocity (V_c). The second velocity of interest is chip velocity (V_f) which is along the tool face. The third is the shear velocity (V_s) which is the speed of chip relative to workpiece. The vector sum of cutting velocity and chip velocity is equal to shear velocity. These velocities have been shown in fig. 2.11.

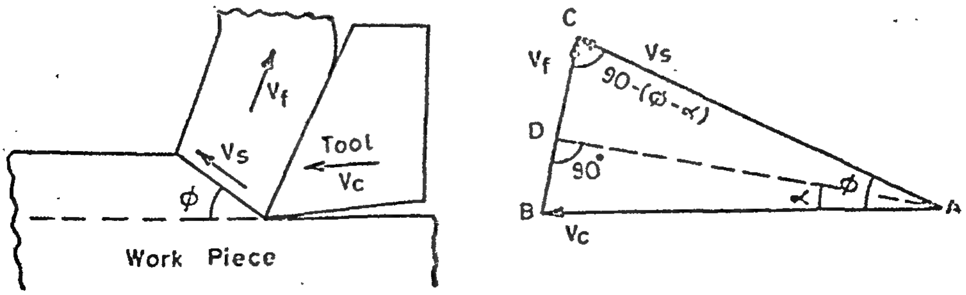


Fig. 2.11 Velocity Relationship

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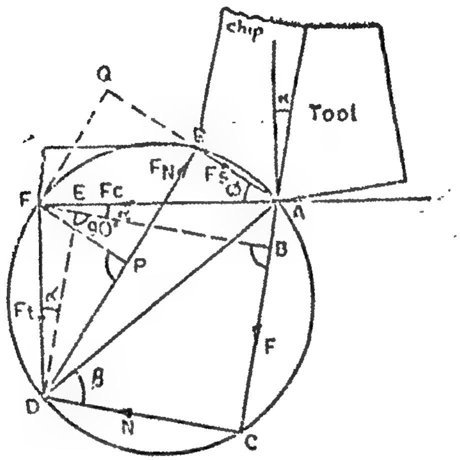

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$$\frac{F_c}{F_s} = \frac{\cos (\beta - \alpha)}{\cos (\phi + \beta - \alpha)}$$

or $$F_c = F_s \times \frac{\cos (\beta - \alpha)}{\cos (\phi + \beta - \alpha)} \qquad \ldots\ 2.09$$

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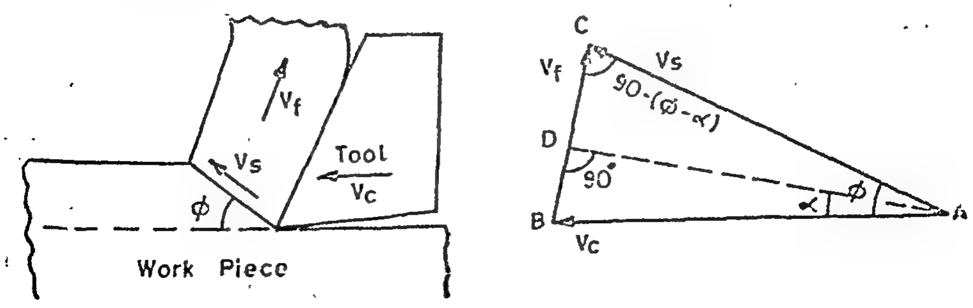

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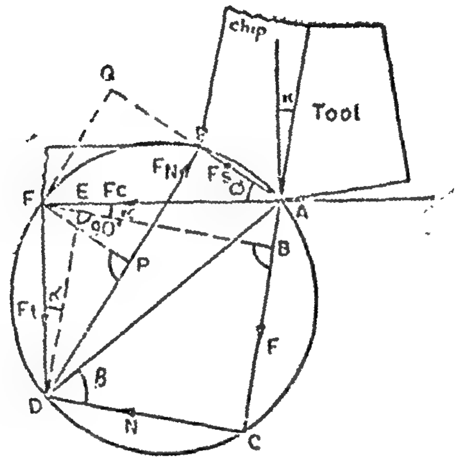

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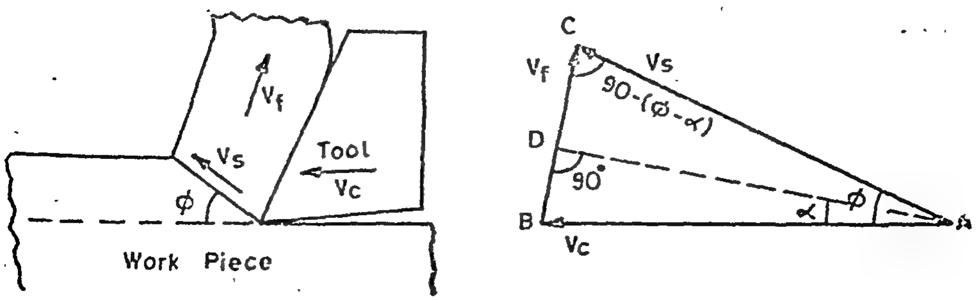

Fig. 2.11 Velocity Relationship

Using trigonometric principles

$$\frac{V_c}{\sin[90-(\phi-\alpha)]}=\frac{V_f}{\sin\phi}=\frac{V_s}{\sin(90-\alpha)}$$

or
$$\frac{V_c}{\cos(\phi-\alpha)}=\frac{V_f}{\sin\phi}=\frac{V_s}{\cos\alpha}$$

$\therefore$
$$V_s=V_c\frac{\cos\alpha}{\cos(\phi-\alpha)}$$

and
$$V_f=V_c\frac{\sin\phi}{\cos(\phi-\alpha)}=V_c\ \gamma\ \text{M/min} \quad \ldots..2.12$$

2.09. STRESS AND STRAIN IN THE CHIP

Chips are obtained due to the plastic deformation of the metal and thus, the chips experience stresses and strain during the machining operations. The values are always calculated for the conditions at the shear plane where two normal forces F_N and F_s exist.

$$\text{Mean Normal Stress }(\sigma)=\frac{F_N}{A_s}$$

$$=\frac{F_N}{A_o}\sin\phi$$

$$=\frac{(F_c\sin\phi+F_t\cos\phi)}{A_o}\sin\phi\ \frac{kg}{mm^2}$$

(where $A_o=b_1\times t_1$) 2.13

$$\text{Mean Shear Stress }(\tau)=\frac{F_s}{A_s}$$

$$=\frac{(F\cos\phi-F_t\sin\phi)}{A_o}\sin\phi\ \frac{kg}{mm^2}$$

Shear strain (γ) is defined as the deformation per unit length. Thus, for the simple case given in (fig. 2.12) and considering the equation (2.09) it can be written

$$F_c=\frac{A_s\times\tau\times\cos(\beta-\alpha)}{\text{Cos}(\phi+\beta-\alpha)} \quad \ldots...2.15$$

$$\frac{\tau a_1 b_1\cos(\beta-\alpha)}{\sin\phi\cos(\phi+\beta-\alpha)} \quad \ldots...2.16$$

Let shear strain (γ) be defined as the deformation per unit length.

$$r = \frac{\delta_s}{\delta_y} \qquad \ldots\ldots 2.17$$

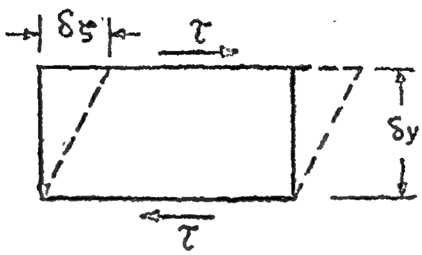

Fig. 2.12 Definition of Strain

In order to obtain the value of (γ) let the chip be composed of a large number of elements of thickness d_y. Each element suffers a displacement δ_s after crossing the shear plane. Considering fig. 2.13.

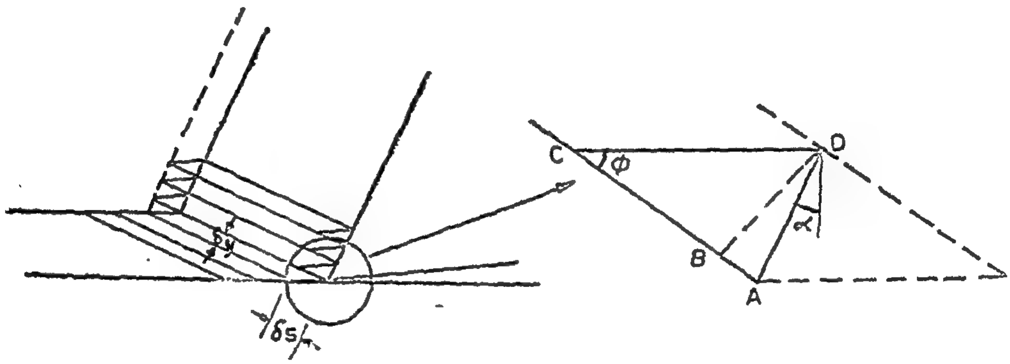

Fig. 2.13 Elements of chip in strained state.

$$\gamma = \frac{\delta_s}{\delta_y} = \frac{AC}{BD}$$

$$= \frac{AB}{BD} + \frac{BC}{BD}$$

$$= \tan(\phi - \alpha) + \cot \phi \qquad \ldots\ldots 2.18$$

$$= \frac{\cos \alpha}{\sin \phi \cos(\phi - \alpha)}$$

Since $\quad V_s = \dfrac{\cos \alpha}{\cos(\phi + \alpha)} \times V_c$

$\therefore \quad V_s = r \times \sin \phi \times V_c \qquad \ldots\ldots 2.19$

And, strain rate $\dot{\gamma} = \dfrac{\delta_s}{\delta_y} . \delta_t$

Using trigonometric principles

$$\frac{V_c}{\sin[90-(\phi-\alpha)]}=\frac{V_f}{\sin\phi}=\frac{V_s}{\sin(90-\alpha)}$$

or
$$\frac{V_c}{\cos(\phi-\alpha)}=\frac{V_f}{\sin\phi}=\frac{V_s}{\cos\alpha}$$

$\therefore$
$$V_s=V_c\frac{\cos\alpha}{\cos(\phi-\alpha)}$$

and
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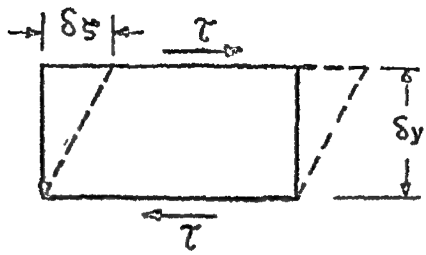
Let shear strain (γ) be defined as the deformation p..

$$r=\frac{\delta_s}{\delta_y} \qquad \ldots\ldots 2.17$$



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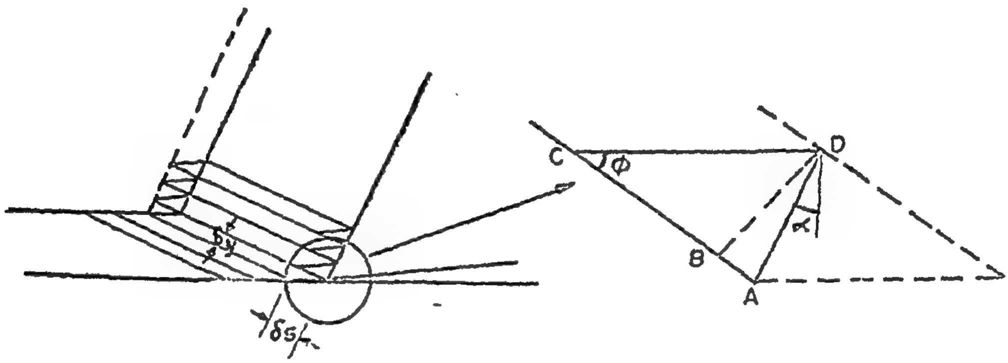


Fig. 2.13 Elements of chip in strained state.

$$\gamma=\frac{\delta_s}{\delta_y}=\frac{AC}{BD}$$

$$=\frac{AB}{BD}+\frac{BC}{BD}$$

$$=\tan(\phi-\alpha)+\cot\phi$$

And

(A) Due to Ernst-Merchant

Ernst-Merchant initially established a relationship on following two assumptions—

(*i*) Expenditure of energy is minimum in the process, *i.e.*, shear will take place in a direction in which energy required for shearing is minimum.

(*ii*) shear stress is maximum at the shearplane and it remains constant.

Considering the equation 2.16 for the cutting force and applying the assumption stated above the following analysis can be applied—

$$F_c = \frac{\tau . a_1 b_1}{\sin \phi} \cdot \frac{\cos(\beta-\alpha)}{\cos(\phi+\beta-\alpha)}$$

Differentiating with respect to ϕ—

$$\frac{dF_c}{d\phi} = -\tau a_1 b_1 \cos(\beta-\alpha) \times \left[\frac{\cos\phi\cos(\phi+\beta-\alpha)+\sin\phi\sin(\phi+\beta-\alpha)}{\sin^2\phi\cos^2(\phi+\beta-\alpha)}\right]$$

$$=0$$

Thus $\cos\phi\cos(\phi+\beta-\alpha)-\sin\phi\sin(\phi+\beta-\alpha)=0$

or $\cos(2\phi+\beta-\alpha)=0$

which gives $2\phi+\beta-\alpha=\frac{\pi}{2}$ ...2.21

$$r = \frac{\delta_s}{\delta_y} \quad ......2.17$$

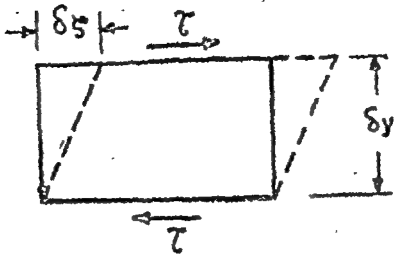


Fig. 2.12 Definition of Strain

In order to obtain the value of (γ) let the chip be composed of a large number of elements of thickness d_y. Each element suffers a displacement δ_s after crossing the shear plane. Considering fig. 2.13.

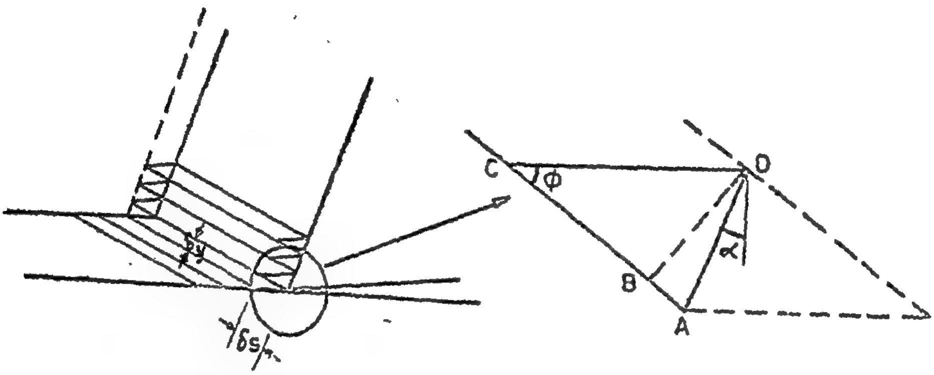


Fig. 2.13 Elements of chip in strained state.

$$\gamma = \frac{\delta_s}{\delta_y} = \frac{AC}{BD}$$

$$= \frac{AB}{BD} + \frac{BC}{BD}$$

$$= \tan(\phi - \alpha) + \cot\phi \quad ......2.18$$

$$= \frac{\cos\alpha}{\sin\phi . \cos(\phi - \alpha)}$$

Since $V_s = \frac{\cos\alpha}{\cos(\phi + \alpha}$

$\therefore$ $V_s = r \times \sin$

And, strain rate $\dot{\gamma} = \frac{\delta}{}$ 2.19

Using trigonometric principles

$$\frac{V_c}{\sin[90-(\phi-\alpha)]}=\frac{V_f}{\sin\phi}=\frac{V_s}{\sin(90-\alpha)}$$

or
$$\frac{V_c}{\cos(\phi-\alpha)}=\frac{V_f}{\sin\phi}=\frac{V_s}{\cos\alpha}$$

$\therefore$
$$V_s=V_c\frac{\cos\alpha}{\cos(\phi-\alpha)}$$

and
$$V_f=V_c\frac{\sin\phi}{\cos(\phi-\alpha)}=V_c\ \gamma\quad \text{M/min} \quad \text{.....2.12}$$

2.09. STRESS AND STRAIN IN THE CHIP

Chips are obtained due to the plastic deformation of the metal and thus, the chips experience stresses and strain during the machining operations. The values are always calculated for the conditions at the shear plane where two normal forces F_N and F_s exist.

$$\text{Mean Normal Stress } (\sigma)=\frac{F_N}{A_s}$$

$$=\frac{F_N}{A_o}\sin\phi$$

$$=\frac{(F_c\ \sin\phi+F_t\cos\phi)}{A_o}\sin\phi\ \frac{kg}{mm^2}$$

(where $A_o=b_1\times t_1$) 2.13

$$\text{Mean Shear Stress } (\tau)=\frac{F_s}{A_s}$$

$$=\frac{(F\cos\phi-F_t\ \sin\phi)}{A_o}\sin\phi\ \frac{kg}{mm^2}$$

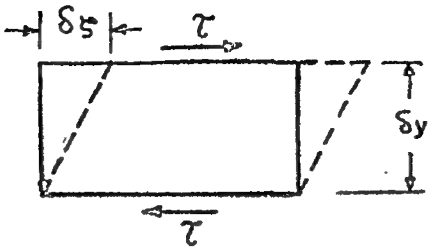
Shear strain (γ) is defined as the deformation per unit length. Thus, for the simple case given in (fig. 2.12) and considering the equation (2.09) it can be written

$$F_c=\frac{A_s\times\tau\times\cos(\beta-\alpha)}{\text{Cos}\ (\phi+\beta-\alpha)} \quad \text{......2.15}$$

$$\frac{\tau a_1 b_1\cos(\beta-\alpha)}{\sin\phi\cos(\phi+\beta-\alpha)} \quad \text{......2.16}$$

Let shear strain (γ) be defined as the deformation per unit length.

$$r = \frac{\delta_s}{\delta_y} \qquad \ldots\ldots 2.17$$



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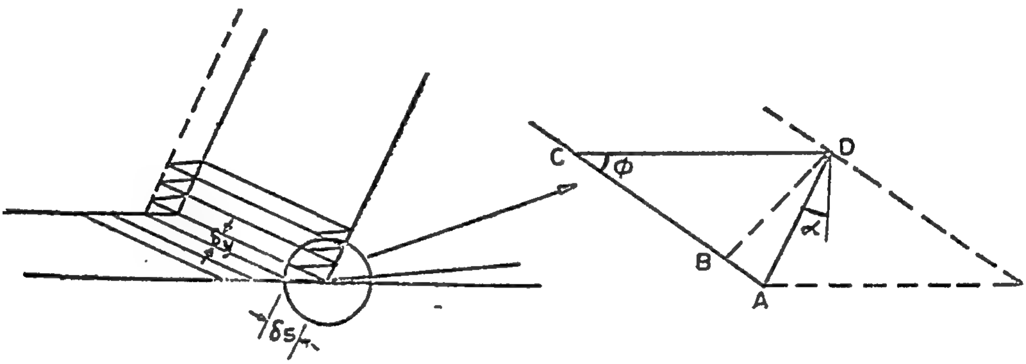

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$$= \frac{AB}{BD} + \frac{BC}{BD}$$

$$= \tan(\phi - \alpha) + \cot \phi \qquad \ldots\ldots 2.18$$

$$= \frac{\cos \alpha}{\sin \phi . \cos(\phi - \alpha)}$$

Since $\quad V_s = \dfrac{\cos \alpha}{\cos(\phi + \alpha)} \times V_c$

$\therefore \quad V_s = r \times \sin \phi \times V_c \qquad \ldots\ldots 2.19$

And, strain rate $\dot{\gamma} = \dfrac{\delta_s}{\delta_y} : \delta_t$

$$=\frac{V_s}{\delta_y}$$

$$=\frac{\cos\alpha}{\cos(\phi-\alpha)}\cdot\frac{V_c}{\delta_y} \qquad \text{......2.20}$$

2.10. THEORIES ON MECHANICS OF METAL CUTTING

All the relationships for forces velocities, energy etc. have been developed in terms of such parameters as rake angle (α) shear angle (ϕ) and friction angle β. Out of these three, α is a measurable quantity, β and ϕ are the quantities which are obtainable by computation. Several investigators have proposed their theories to establish a relationship between ϕ, α and β and an understanding of these theories gives a better insight of metal cutting process to the students. The three well-known theories have been explained in this section.

(A) Due to Ernst-Merchant

Ernst-Merchant initially established a relationship on following two assumptions—

(*i*) Expenditure of energy is minimum in the process, *i.e.*, shear will take place in a direction in which energy required for shearing is minimum.

(*ii*) shear stress is maximum at the shearplane and it remains constant.

Considering the equation 2.16 for the cutting force and applying the assumption stated above the following analysis can be applied—

$$F_c=\frac{\tau.a_1b_1}{\sin\phi}\cdot\frac{\cos(\beta-\alpha)}{\cos(\phi+\beta-\alpha)}$$

Differentiating with respect to ϕ—

$$\frac{dF_c}{d\phi}=-\tau a_1b_1\cos(\beta-\alpha)\times\left[\frac{\cos\phi\cos(\phi+\beta-\alpha)+\sin\phi\sin(\phi+\beta-\alpha)}{\sin^2\phi\cos^2(\phi+\beta-\alpha)}\right]$$
$$=0$$

Thus $\quad \cos\phi\cos(\phi+\beta-\alpha)-\sin\phi\sin(\phi+\beta-\alpha)=0$

or $\quad \cos(2\phi+\beta-\alpha)=0$

which gives $\quad 2\phi+\beta-\alpha=\frac{\pi}{2}$ ...2.21

On comparing the practical and theoretical values of given by 2.21 Merchant found there was no agreement amongst these values. This led to modify his theory by assuming that shear stress (τ_s) along the shear plane varies linearly with normal stress as

$$\tau_s = \tau_0 + k\sigma \qquad \ldots 2.21$$

where τ_0 is the value of τ_s when σ is zero. He then derived

$$2\phi = C + \alpha - \beta \qquad \ldots 2.23$$

In this equation C measures the dependence of shear strength on normal stress. C was termed as machining constant. The most controversial point in the Merchant solution remained with the fact that the friction conditions were independent of ϕ.

(B) Due to Lee & Shaffer : Lee and Shaffer theory is based on ideal theory of plasticity accordingly it was assumed that shear occurs on a single plane ; when this assumption is applied to cutting process it leads to

(*i*) Material ahead of tool behaves as ideal plastic mass

(*ii*) No hardening in chip occurs

(*iii*) There exists a shear plane which separates the chip and workpiece.

The behaviour of cutting process was explained with the help of slip lines at the shear plane as shown in fig. 2·14. Analysis was

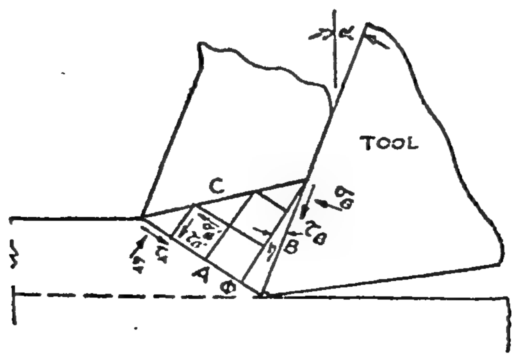


Fig. 2.14. Shear zone model due to Lee & Shaffer

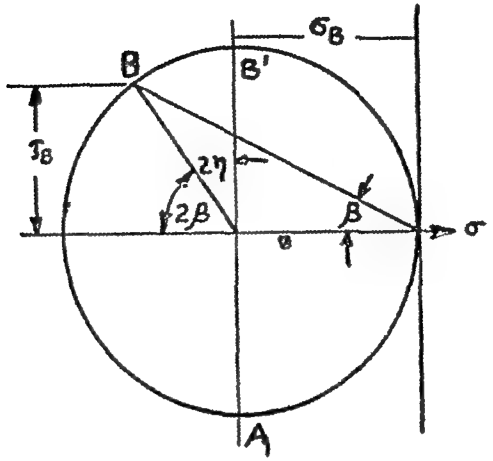


Fig. 2.15. Mohr Circle representing stresses in the shear zone

carried out in a zone ABC with the help of two sets of parallel lines. The zone ABC is formed by shear plane, tool face and an arbitary plane AB the shear across which was derived as zero from the assumed stress free state of the chip and hence the slip lines are inclined 45° to plane AB. The stress conditions were described with the help of a Mohr circle. The circle further provides

$$\beta+\phi-\alpha=\frac{\pi}{4} \qquad \ldots\ldots 24$$

This relation was later found not valid for all values of α and β and due to which Lee and Shaffer had to modify the equation by introducing another parameter (θ) for built up nose formation *i.e.*,

$$\beta+\phi-\alpha-\theta=\frac{\pi}{4} \qquad \ldots 2.25$$

Even this relationship was not widely acceptable due to many the assumption that material behaves as ideal plastic mass.

[C] **Due to Palmer and Oxley :** The observations by these two investigators is based upon a detailed study of mechanics of chip formation on the flow of grains in the material. The grain flow showed a stream lined pattern andthe boundary between elastic and plastic zones wasnot a straight line as assumed by Merchant, Lee and Shaffer. They proposed a narrow wedge shaped zone but for simplicity

they considered that the removed metal chip is formed in a parallel sided shear zone as shown in fig. 2.16.

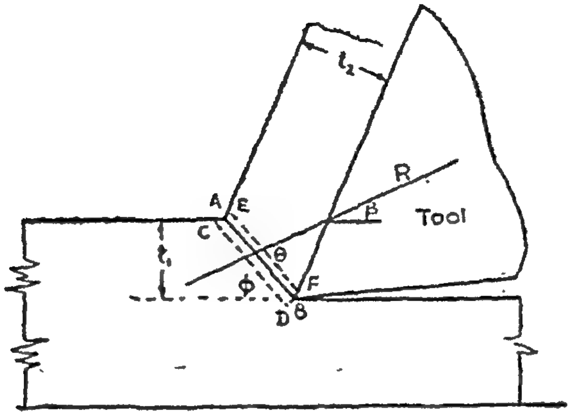


Fig. 2.16. Shear zone model by Oxley

From this diagram it is evident

$$\theta=\phi+\beta-\alpha \qquad ...2.26$$

However, there are many more theories and their results have been tabulated here only for reference.

Table II

Investigators	Year	Relationships
Zvorykin	1896	$\phi=\frac{\pi}{4}+\frac{\alpha}{2}-\frac{1}{2}\text{ arc tan }\mu$ $-1/2\text{ arc tan }\mu_s$
Bricks	1896	$\phi_2=\frac{\pi}{4}+\frac{\alpha}{2}-\frac{1}{2}\text{ arc tan }\mu-\frac{\alpha,}{2}$
Ernst & Merchant	1941	$\phi=\frac{\pi}{4}-\frac{\beta}{2}+\frac{\alpha}{2}$
Merchant	1945	$\phi=\frac{\text{arc cot } k}{2}-\frac{\beta}{2}+\frac{\alpha}{2}$
Stabler	1951	$\phi=\frac{\pi}{4}-\beta+\frac{\alpha}{2}$
Lee & Shaffer	1951	$\phi=\frac{\pi}{4}-\beta+\alpha$
		$\phi=\frac{\pi}{4}+\theta-\beta+\alpha$

Hucks	1951	$\phi=\frac{\pi}{4}+\alpha-ax\frac{\tan 2\mu}{2}$
Shaw, Cook, Finnie	1953	$\phi=\frac{\pi}{4}-\beta+\alpha+\eta^1$
Zorev	1956	$2\phi+\beta-\alpha=90°-\xi$
Kronenberg	1957	$\phi=\text{arc}\cot\left[\frac{e\mu\left(\frac{\pi}{2}-\alpha\right)}{\cos\alpha}-\tan\alpha\right]$
Hitomi & Okushima	1957	$\phi_1=\frac{k^1}{2}-\frac{\beta}{2}+\frac{\alpha}{2}$
		$\phi_2=\frac{k_2}{2}-\frac{\beta}{2}+\alpha$
Kobayashi & Thomson	1962	$2\phi=\text{arc}\sin[\eta+(1-\eta)\sin(\beta-\eta)]-(\beta-\alpha)$
Loladze	1965	$\tan(\phi+\beta-\alpha)=1+\phi-\alpha+\frac{\sin 2(\phi-\alpha)}{2}$
Albrecht	1966	$\phi=\frac{\pi}{4}+\frac{\alpha}{2}+\frac{k^1}{2}$

2.11 POWER AND ENERGY RELATIONSHIPS

The energy consumed during the cutting process is primarily utilized at the shear plane, where the plastic deformation takes place and at chip tool interface, where friction resists the flow of chip. The total energy per unit volume (E) is approximately equal to the sum of following two energies.

1. E_s—shear energy/unit volume on shear plane.
2. E_f—friction energy/unit volume on tool face.

Total energy per unit time $(E_0)=F_c\ V_c$ kg mm/min ... 2.27

Total energy per unit volume

of metal removed $=\frac{E_0}{V_c\times b_1\times t_1}$

$$=\frac{F_c\times V_c}{b_1\times t_1\times V_c}$$

$$=\frac{F_c}{b_1\times t_1}\ \text{kg/mm}^2 \quad ...2.28$$

and $$E_s = \frac{F_S \times V_c}{V_c \times b_1 \times t_1}$$

$$= \frac{\tau \times V_s}{V_c \times \sin\phi} \quad \text{kg/mm}^2 \qquad ...2.29$$

$$E_f = \frac{F_N \times V_t}{V_c \times b_1 \times t_1}$$

$$= \frac{F_N \times V_t}{b_1 \times t_1} \quad \text{kg/mm}^2 \qquad ...2.30$$

Besides, there are two more components which are parts of the total specific energy. One of the components relates to the specific surface energy (E_a) and the other one is specific momentum energy (E_m). As the metal passes through the shear zone, its direction of movement falls parallel to the shear plane. This sudden change in velocity is at the cost of momentum energy. Applying the linear momentum principle along the shear plane, the value of resultant force F_M can be written as

$$F_M = \rho V_c b_1 t_1 [V_1 \sin(\phi - \alpha) + V_c \cos\phi] \qquad 2.31$$

$$= \rho V_c b_1 t_1 V_c \gamma \sin\phi$$

$$E_M = \frac{F_M V_s}{V_c b_1 t_1}$$

$$= \frac{V_c^2 b_1 t_1 \gamma \sin\phi \, V_s}{V_c b_1 t_1}$$

$$= \gamma \rho V_c \sin\phi \, V_t$$

$$= \gamma^2 \rho V_c^2 \sin^2\phi \qquad ...2.32$$

Both the components E_a and E_M are very small in the magnitude and hence, they are neglected in the computation.

2.12 THERMAL ASPECT OF METAL MACHINING

Considerable heat is generated at the cutting edge while machining metal on the machine tool. Therefore, the machine tool may be treated as inverse heat engine. In a heat engine, the heat energy is used to produce mechanical energy ; where as, mechanical energy is supplied to the machine tool and heat energy is observed at the cutting edge during machining.

While machining, the heat is evolved at three zones, (fig. 2.17). Zone A is known as shear zone where the maximnm heat is generated because of the plastic deformation of metal. Almost all of the heat is carried away by the chip as machining is a rapid and continuous process. A very minor percentage of this heat may be conducted to workpiece, which ranges from 5% to 10% of total heat due to deformation at shear zone.

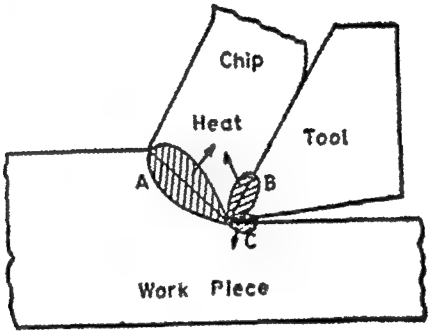


Fig. 2.17 Heat zones represented on work-chip-tool model

Zone B is friction zone, where the heat is generated due to friction between moving chip and tool face, and secondary deformation of the built-up edge. The chip flows along the tool face under great pressure and its movement is resisted by friction at the interface.

Zone C is work-tool contact zone. Here too, the heat is generated due to burnishing friction. When the machining starts with a fresh tool, the friction is almost nil. But as the process continues, wearland develops and goes on increasing. This increase is responsible for generation of more and more heat as the process continues.

The arrows in the fig, 2.17 indicate the direction of maximum percentage of heat flow from each zone. There is always some heat flowing in the directions other than those indicated by arrows.

Each of these heat zones contributes to the rise of temperature at the tool-chip interface which is the main enemy of the cutting tool. High temperature at the cutting edge leads to the failure of the tool both by softening and thermal stresses. It has been shown by

Trigger and Chao that this temperature is never maximum at the cutting edge but is slightly away from the edge and at about middle of the chiptool contact length. These investigators have also established that this temperature plays a major role on the formation of crater on the tool face.

EFFECT OF THE MACHINING VARIABLES

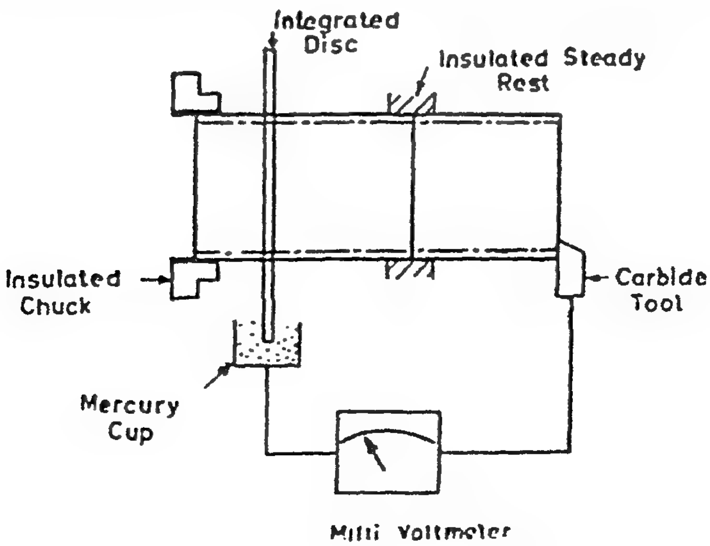
Of all the variables encountered in machining of steels, speed has the maximum influence on the tool temperature. The next variable is the cutting feed. Properties of material have a definite influence on the temperature. They affect the size of shear zone and chip-tool contact length and thereby, the area over which heat is distributed. Shorter length of contact would lead to severe temperature rise on the chip-tool interface.

2 13 MEASUREMENT OF CHIP TOOL INTERFACE TEMPERATURE

The average temperature of the chip-tool interface can be obtained in the laboratory either by tool-work thermocouple technique or by caloriemetric set-up.

1. Tool-Work Thermocouple

In the case of tool work thermo-couple technique the hot junction is due to heat at chip-tool junction. The *e. m.f.*, developed is measured by a suitable millivoltmeter which is callibrated for reading temperature with the help of an amplifier (fig. 2.18). This set up is very suitable for carbide tools when 10-15 mv reading is obtained. The millivoltmeter hardly shows 2-3 mv. with H.S.S. tools.



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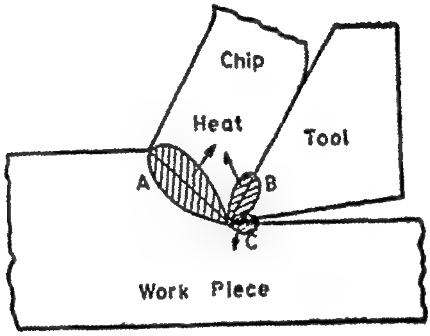

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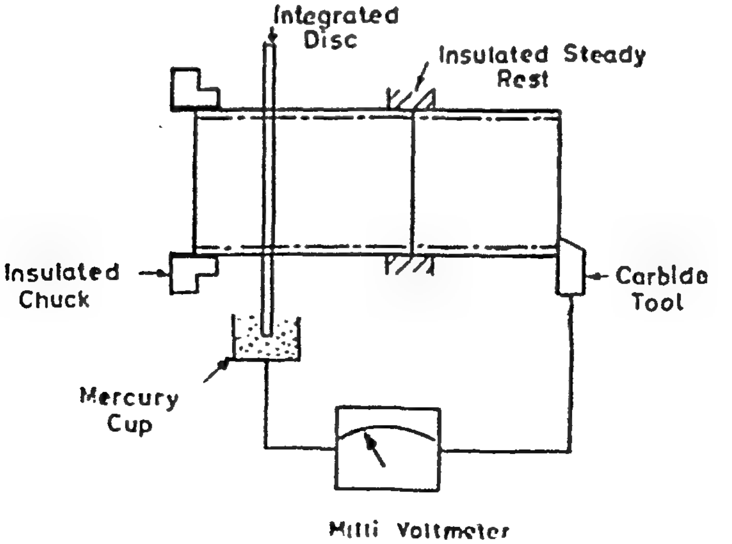

Fig. 2.18 Thermocouple Set Up

2. Caloriemetric Set-up :

Calorimetric set up was introduced by Prof. Sawwin of Leningrad Polytechnic, in 1912. He used a calorimeter and dynamometer on a lathe for investigating the effect of cutting fluid on metal machining. Later on, Dr. A.O. Schmidt developed suitable caloriemeters for drilling and milling tests (Fig. 2.19) and evaluated machinability of several alloys of aluminium and magnesium. The average chip tool interface temperature has been determined by the procedure of thermal balance :

Heat in calorimeter $= \delta T \times$ Water equivalent of (calorimeter + water + chips).

Heat given by chips $= T_c \times$ chip weight $\times$ sp. heat.

As heat in calorimeter is equal to heat given by chip, therefore,

$$\delta T \times W = T_c \times W_c \times S$$

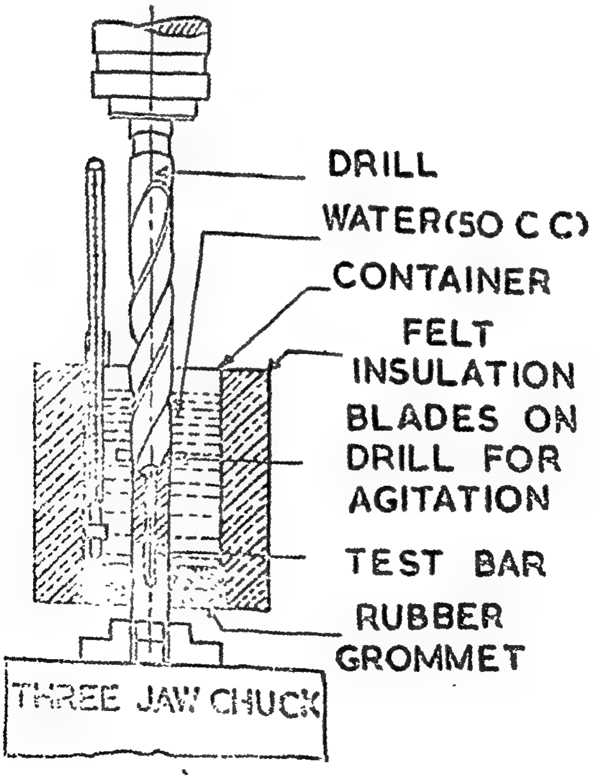

Fig. 2.19 Caloriemetric Set-up (After A.O. Schmidt)

Where δT=rise in calorimeter temperature

W=water equivalent of calorimeter, chips and water

T_c=Average chip temperature

W_c=Weight of chips

S=Sp. heat of the chip

$$\therefore \quad T_c = \frac{\delta T \times W}{W_c \times S} \qquad \text{...2.33}$$

On keeping the workpice immeresed in water, it is possible to withdraw the amount of heat going to workpiece and then work out the heat in chip and workpiece. Similarly, if cutter performs the machining while in water, it is possible to determine the total heat energy being developed while machining. Thus, it is possible to compute the proportions of heat in chip, workpiece and the tool. This distribution as reported by Schmidt is 80%, 10% and 10% respectively (fig. 2.20). However, it must be kept in mind that Schmidt's

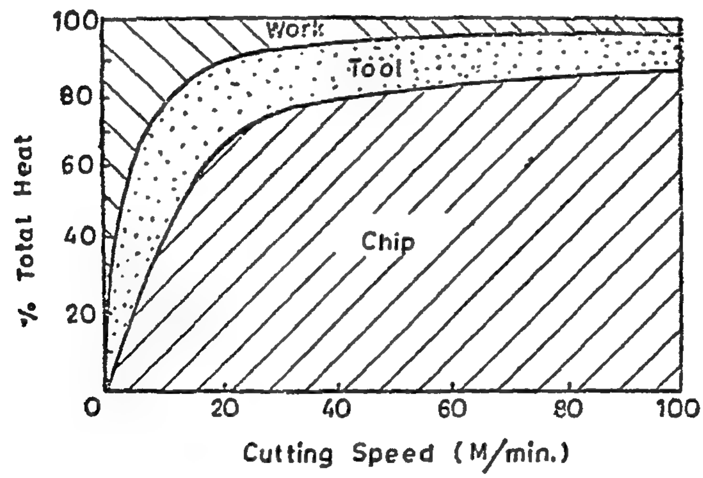

Fig. 2.20 Heat Distribution in Chips, Tool & Work

conclusion is only true with carbide cutters and that too, at cutting speeds 30M/min and above.

2.14 FRICTION IN METAL CUTTING

The higher value of coefficient of friction (μ) observed by many investigators led them to study the behaviour of chip on the rake face of the tool. Amonton's laws of friction were not applicable to the

conditions existing at the rake face. Zorev established in 1948 and in his subsequent works that the sliding of chip on tool face is composed of two zones C_1 and C_2 fig. 2.21. In the zone C_1 may be

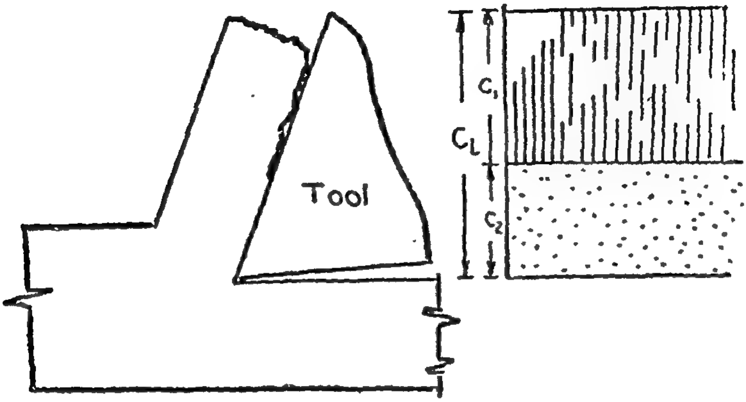

Fig. 2.21 Stick and sliding zones at rake face

called sticking region and C_2 may be called sliding region. The texture of zone C_1 is different from C_2 which is composed of longitudinal scratches. Due to sticking contact and sliding contact the laws for the variation in the coefficient of friction principally differ very much. The sticking contact has been attributed due to high tangential loads which refered the contact layer of the chip and ultimately leads to secondary shear of metal.

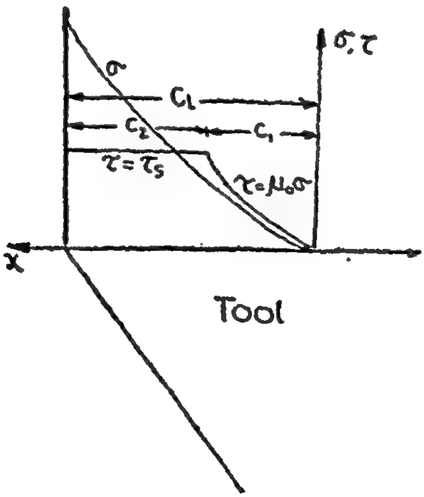

Fig. 2.22 Variation in the normal and tangential contact stresses (zones)

It has been observed that normal stresses in the contact zone is non-uniform. At the point where chip leaves the face it is zero and it increased as the cutting edge is approached (fig. 2.22.) where it is maximum. Schematical distribution of normal and tangential stresses on the tool face may berepresented in the from of curves given in fig. 2.22 It is due to this fact that the values of coefficient of friction is always greater than one. The measured value is taken as an average of the coefficients of friction for the two zones C_1 and C_2.

Example 1. *A seamless tubing 35 mm outside diameter is turned on a lathe. The following data are available ; rake angle—35° cutting speed 15M/min, feed—0.10 mm/rev, length of continuos chip in one revolution=50 mm, cutting force—200 kg, feed force 80 kg. Calculate the coefficlent of friction, shear plane angle, velocity of chip along tool face and chip thinkness.*

Solution :

(*i*) Coefficient of friction (μ)

$$=\frac{Ft+F_c \tan \alpha}{F_c-Ft \tan \alpha}$$

$$=\frac{80+200\times 0.7}{200-80\times 0.7}$$

$$=\frac{220}{144}$$

$$=1.525.$$

(*ii*) Shear plane angle ϕ

$$rt=\frac{t_1}{t_2}=\frac{l_2}{l_1}=\frac{60}{\pi\times 35}$$

$$=0.525$$

$$\because \tan \phi=\frac{0{\cdot}525\times \cos \alpha}{1-0{\cdot}525\times \sin \alpha}$$

$$=\frac{0{\cdot}525\times 0{\cdot}82}{1-0{\cdot}525\times 0{\cdot}575}$$

$$=2{\cdot}625$$

$$\phi=32°,$$

(*iii*) Chip Velocity (V_f)

$$V_f = V \times r_t = 15 \times 0\ 525$$
$$= 7{\cdot}875 \text{ M/min.}$$

(*iv*) Chip thickness (t_2)

$$t_2 = \frac{t_2}{r_t}$$
$$= \frac{0{\cdot}1}{0{\cdot}525}$$
$$= 0{\cdot}191 \text{ mm.}$$

Example 2. *In an orthogonal cutting test on a m.s. tube of size 150 mm diameter and 2.1 mm thickness, conducted at 90 meters per minute and 0·21 mm/rer. feed, the following data were recorded*

Cutting force	*=125 kg*
Feed force	*=30 kg*
Chip thickness	*=0·3 mm*
Contact length	*=0·75 mm*
Net horse power	*=2 kw*
Back Rake	*=−10°*

Compute shear strain, strain energy per unit volume

Solutlon :

$$rt = 0{\cdot}21/0{\cdot}3 = 0{\cdot}70$$
$$\tan \phi = \frac{0{\cdot}73 \cos(-10)}{1 - 0{\cdot}70 \sin(-10)}$$
$$= \frac{0{\cdot}70 \times 0{\cdot}984}{1 + 0{\cdot}70 \times 0{\cdot}173}$$
$$= \frac{0{\cdot}686}{1{\cdot}121}$$
$$= {\cdot}615$$
$$\phi = 3{\cdot}15°$$

(*ii*) Shear strain $= \tan(\phi - \alpha) + \cot \phi$

$$= \tan(31{\cdot}5 + 10) + \cot 31{\cdot}5$$
$$= 0{\cdot}884 + 1{\cdot}631$$
$$= 2{\cdot}515.$$

(*ii*) Strain Energy per unit volume

$$=\text{Shear stress} \times \text{shear strain}$$

$$\text{Shear stress} = \frac{F_s}{A_s}$$

$$= \frac{F_c \cos\phi - F_t \sin\phi}{A_o} \times \sin\phi$$

$$= \left(\frac{125 \times 852 - 30 \times 0{\cdot}522}{.021 \times 2{\cdot}1}\right) \times 0{\cdot}522$$

$$\frac{106{\cdot}5 - 15{\cdot}660}{\cdot 441} \times 0{\cdot}522$$

$$= 90{\cdot}740 \times 1{\cdot}185$$

$$= 107{\cdot}2 \text{ kg/mm}^2$$

$$\therefore \text{ Shear Energy } = 107{\cdot}2 \times 2{\cdot}515$$

$$= 270 \text{ kg/mm}^2.$$

Example 3 : *Prove that the specific cutting pressure in an ideal orthogonl cutting is 2 S_c cot ϕ if $2\phi + \beta - \alpha = \frac{\pi}{2}$*

Solution :

$$\text{Specific cutting pressure} = \frac{F_c}{A_o \sin\phi}$$

From the Merchants force diagram we have

$$F_c = R \cos(\beta - \alpha)$$

$$F_s = R \cos(\phi + \beta - \alpha)$$

$$\therefore F_c/F_s = \frac{\cos(\beta - \alpha)}{\cos(\phi + \beta - \alpha)}$$

Also, from the given relationship

$$\beta - \alpha = \left(\frac{\pi}{2} - 2\phi\right)$$

$$\therefore \quad F_c = \frac{F_s \cos\left(\frac{\pi}{2} - 2\phi\right)}{\cos\left(\phi + \frac{\pi}{2} - 2\phi\right)}$$

$$= \frac{F_s \sin 2\phi}{\sin\phi}$$

$= 2\ F_s \cos\phi$

$\therefore$ Sp. cutting Pressure

$$= \frac{2\ F_s \cos\phi}{A_o \sin\phi}$$

$$= 2\ S_c \cos\phi$$

Example : *While conducting an experiment with a calorimeter in drilling operation to study the heat distribution in chip, tool and workpiece the following data were rccorded—*

Test Piece = Aluminuim

Water Equivalent

of calorimeter = 18·4 gr.

Spindle rpm = 540

feed—0·10 mm/rev.

length of cut = 25 mm

Temperature Rise = 10°C

Water in calorimeter = 50c.c

Outside diameter of drill = 7mm

Inside diameter of drill = 2mm

Density of Al = 2·60 gm/cc

Specific heat of Al = ·214

Calculate average chip temperature and horse power per cc of metal.

Solution :

From eq^n 2·23

$$T_c = \frac{\delta T \times w}{w_c \times S}$$

Where $w_c = \frac{\pi}{4}(d_o^2 - d_i^2) \times l \times \text{sp. gr}$

$$= \frac{\pi}{4}(49-4) \times 25 \times 2{\cdot}6$$

$$= 2{\cdot}30 \text{ gm}$$

$$\therefore \quad T_c = \frac{10 \times 18{\cdot}4}{2{\cdot}3 \times {\cdot}214}$$

$$= 370°\text{C}$$

$$\text{Time of cutting} = \frac{25}{540 \times \cdot 10}$$

$$= 0 \cdot 464 \text{ min.}$$

Heat developed $= 68 \cdot 4 \times 10$ gm calori per $0 \cdot 464$ min

$$\text{Heat per unit time} = \frac{684}{0 \cdot 464} = 1480 \text{ gm. calori/mm}$$

Since HP (metric) $= 10530$ gm cal per min

$$\therefore \text{ HP from Heat} = \frac{1480}{10530}$$

$$= 0 \cdot 14$$

$$\text{Volume of metal/min} = \frac{\pi}{4}(49-4) \times 0 \cdot 10 \times 540$$

$$= 1800 \text{ mm}^3$$

$$= 1 \cdot 8 \text{cc}$$

$$\text{HP per cc of metal} = \frac{0 \cdot 14}{1 \cdot 8}$$

$$= 0 \cdot 077.$$

Note : 1 HP (metric) $= 75$ m kg f/sec

$$J = 427 \text{ mkgf/k. cal}$$

$$= \frac{75}{427} \text{ k cal/sec}$$

$$= \frac{75 \times 1000}{427} \text{ gm cal/sec}$$

$$= 175 \cdot 5 \text{ gm cal/sec}$$

$$= 10530 \text{ gm cal/min.}$$

Example 4. *In an orthogonal cutting test on an aluminium alloy the following values have been recorded* $\alpha = 20°$, $t_1 = 0 \cdot 12$ *mm*, $b_2 = 4 \cdot 00$ *m* $b_1 = 3 \cdot 75$ *mm*, $\tau = 20$ *kg/mm*^{2}, $l_c = 35$ *mm*, $l = 150$ $\mu = 0 \cdot 77$, $V_c = 30$ *M/min,. Determine forces and power consumption.*

Solution :

By eq^n 2·20

$$l_1 b_1 t_1 = t_2 l_2 b_2$$

$$\therefore \quad \frac{t_1}{t_2} = \frac{l_2 b_2}{l_1 b_1}$$

$$= \frac{35 \times 4}{150 \times 3{\cdot}75}$$

$$r_t = 0{\cdot}248$$

$$\therefore \quad \tan\phi = \frac{r_t \cos\alpha}{1 - r_t \sin\alpha}$$

$$= \frac{0{\cdot}248 \times 0{\cdot}936}{1 - 0{\cdot}248 \times 0{\cdot}342}$$

$$= \frac{0{\cdot}233}{0{\cdot}915}$$

$$= 0{\cdot}254$$

$$\therefore \quad \phi = 14{\cdot}5^\circ$$

$$\text{Sin } \phi = 0{\cdot}250$$

$$\text{Cos } \phi = 0{\cdot}968$$

$$\tan\beta = \mu = 0{\cdot}77$$

$$\therefore \quad \beta = 37{\cdot}5$$

$$\therefore \quad \beta - \alpha = 17{\cdot}5$$

$$\text{Cos }(\beta - \alpha) = .953$$

$$\text{Cos }(\phi + \beta - \alpha) = {\cdot}848$$

$$\text{As } F_c = \frac{\tau\, t_1\, b_1}{\text{Sin }\phi} \times \frac{\text{Cos }(\beta - \alpha)}{\text{Cos }(\phi + \beta - \alpha)}$$

$$= \frac{30 \times 0{\cdot}12 \times 3{\cdot}75}{0{\cdot}250} \times \frac{0{\cdot}953}{0{\cdot}848}$$

$$= 66{\cdot}75 \text{ kg}$$

$$\text{Also } \frac{F_t}{F_c} = \tan(\beta - \alpha)$$

$$\therefore \quad F_t = F_c \tan(17{\cdot}5)$$

$$= 66{\cdot}75 \times 0{\cdot}315$$

$$= 21{\cdot}00 \text{ kg}$$

$$\text{Power Consumption} = \frac{F_c \times V_c}{60 \times 75}$$

$$= \frac{66{\cdot}75 \times 30}{60 \times 75}$$

$$= 0{\cdot}44 \text{ HP.}$$

QUIZ

1. Bring out salient features of various types of single point tools used in the machining of metals.
2. Name the parameters of a single point tool in their proper scquence.
3. Differentiate between orthogonal and oblique cutting methods.
4. Draw Merchant's force diagram. State the assumptions made in the development of such a diagram.
5. Define chip reduction coefficient (k).
6. Prove that the strain in the chip is minimum when the value of chip reduction coefficient is unity.
7. Prove that $\gamma=\dfrac{k^2-2k \sin \alpha+1}{k \cos \alpha}$

   where γ=shear strain

   k=chip reduction coefficient

   α=rake angle
8. "A machine tool is inverse of heat engine." Justify
9. What are various ways of determining average temperature at the cutting edge ?
10. How would you obtain the amount of heat in chip tool and work by using a calorimeter ?
11. During orthogonal cutting with 10° rake tool the following observations were made F_t=30 kg F_c=100 kg feed=0.05 mm. Determine coefficient of friction, shear stress, work done in overcoming chip tool friction and the work done in shearing unit volume of the material. Assume that the depth of cut=1.0 mm.

   Ans. *0.502, 558 kg/mm², 1695 kg/mm² 1615 kg/mm²*

$$\therefore \quad \frac{t_1}{t_2} = \frac{l_2 b_2}{l_1 b_1}$$

$$= \frac{35 \times 4}{150 \times 3{\cdot}75}$$

$$\therefore \quad r_t = 0{\cdot}248$$

$$\tan \phi = \frac{r_t \cos \alpha}{1 - r_t \sin \alpha}$$

$$= \frac{0{\cdot}248 \times 0{\cdot}936}{1 - 0{\cdot}248 \times 0{\cdot}342}$$

$$= \frac{0{\cdot}233}{0{\cdot}915}$$

$$= 0{\cdot}254$$

$$\therefore \quad \phi = 14{\cdot}5^\circ$$

$$\text{Sin } \phi = 0{\cdot}250$$

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$$\therefore \quad \beta = 37{\cdot}5$$

$$\therefore \quad \beta - \alpha = 17{\cdot}5$$

$$\text{Cos } (\beta - \alpha) = .953$$

$$\text{Cos } (\phi + \beta - \alpha) = {\cdot}848$$

$$\text{As } F_c = \frac{\tau\, t_1\, b_1}{\text{Sin } \phi} \times \frac{\text{Cos } (\beta - \alpha)}{\text{Cos } (\phi + \beta - \alpha)}$$

$$= \frac{30 \times 0{\cdot}12 \times 3{\cdot}75}{0{\cdot}250} \times \frac{0{\cdot}953}{0{\cdot}848}$$

$$= 66{\cdot}75 \text{ kg}$$

$$\text{Also } \frac{F_t}{F_c} = \tan (\beta - \alpha)$$

$$\therefore \quad F_t = F_c \tan (17{\cdot}5)$$

$$= 66{\cdot}75 \times 0{\cdot}315$$

$$= 21{\cdot}00 \text{ kg}$$

$$\text{Power Consumption} = \frac{F_c \times V_c}{60 \times 75}$$

$$= \frac{66{\cdot}75 \times 30}{60 \times 75}$$

$$= 0{\cdot}44 \text{ HP:}$$

CHAPTER III

MECHANICS OF MULTIPOINT CUTTING TOOLS

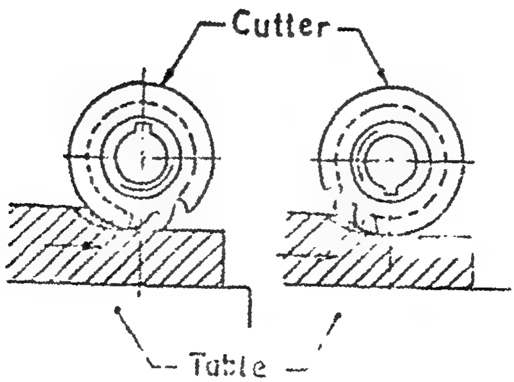
3.1. MILLING

The special feature of the milling process is that the rotating tool has a number of cutting edges each of which works over only a part of its rotary path and remains idle during the remainder. The cutting movement in this case is due to the rotation of the cutter whereas the feed movement is provided by the movement of the table to which the work-piece is usually clamped.

3.1.1. Milling Cutters :

The position of the teeth relative to the cutting surface can be accepted as a criterion for cutter classification. Some of the milling cutters have already been shown in figs. 1.12 and 1.13.

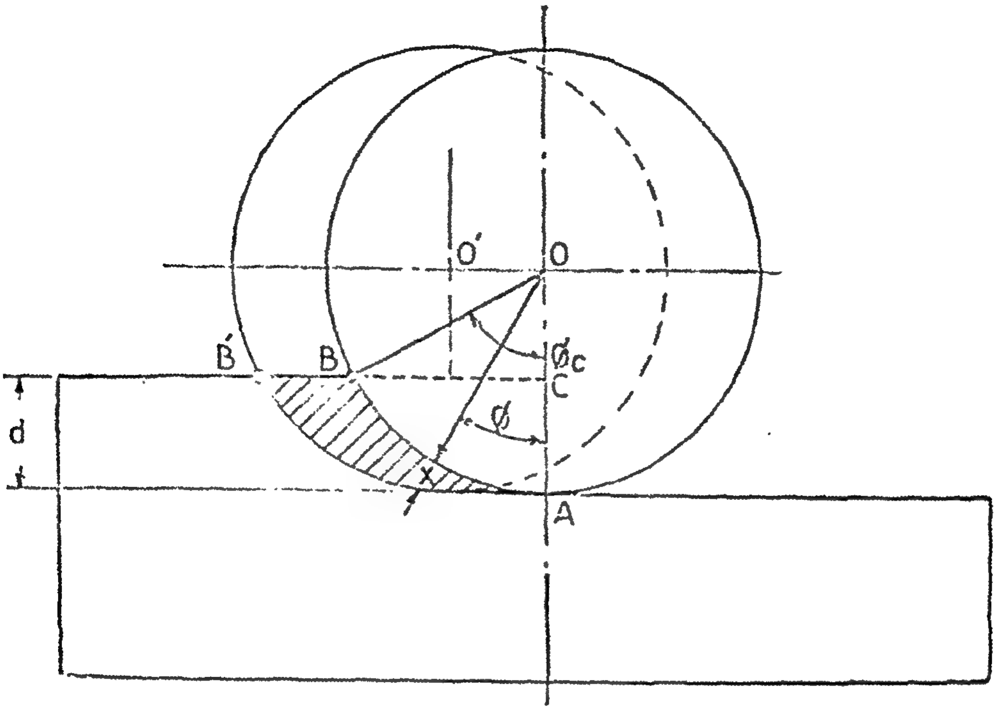
3.1.2 Conventional milling and climb milling.



Figs. 3.1. (*a*), (*b*)

12. While machining SAE 4130 steel with a carbide tool, 0, 5, 6, 6, 8, 90, 1 mm (according to I.S.O.) at $V_c = 180$ meters per min, $f = 0.2$ mm/rev and $d = 2.0$ mm a chip thickness of 0.42 mm was measured. If the value of dynamic shear stress is 40 kg/cm², calculate the cutting force F_c employing Merchant's modified relationship in which $2\phi + \beta - \alpha = 77°$

Ans. 48 kg.



$$OC=\left(\frac{D}{2}-d\right)$$

$$OB_1=\frac{D}{2}$$

$$B_1C=\sqrt{\frac{D^2}{4}-\left(\frac{D}{2}-d\right)}=\sqrt{d(D-d)}$$

Fig. 3.2

If the teeth of the cutter are straight, i e, the helix angle is zero then the width of cut at any instant will be the same as the width of the work piece "W". Therefore crossectional area of the chip at any instant is given by

$$A=W.\frac{f}{N.n_t}\sin\phi$$

Maximum crossectional area,

$$A_{max}=\frac{2fW.\sqrt{d(D-d)}}{D.N.n_t} \quad \text{.. (3.3a)}$$

Assuming that the mean crossectional area (A_m) of the chip to equal to $=\frac{A_{max}}{2}$

Figs. 3.1 (*a*) shows a convential or upmilling operation. In this case the tooth does not start cutting at a point directly below the spindle. It tends to skid over there for a small distance across the surface machined by the preceding tooth. This results in rapid wear of the cutter on the relieved land. The crossection of the chip produced in this case is as shown shaded. In climb or down milling the tooth starts the cut at the surface and leaves the work. In this case the cut begins immediately without sliding and hence less wear of the relieved land. However, as the direction of cutting in this case is same as the feed direction it can not be used on machines having back-lash in the table feeding mechanism Also in this case as the cutter starts the cut from the unmachined outerskin towards the inside the cutter is quickly dulled whilst machining castings and *forgings etc. Climb milling is particulary useful in slitting* and cutting off operations of thin work pieces.

3.1.2 Chip Crossection

(*a*) Plain milling cutter

The crossection of the chip produced by a Single tooth during milling will be the one confined within two arcs of a radius equal to one half milling cutter diameter (fig. 3.2).

The tooth contact angle ϕ_0 depends upon the diameter of the milling cutter D, depth of cut "*d*" and is given by

$$\cos \phi_0 = \frac{D - 2d}{D} \qquad \text{.. (3.1)}$$

Chip thickness for any angle of cutter rotation "ϕ" is given by

$$x = f_t \sin \phi \qquad [f_t = \text{feed per tooth "mm"}] \qquad \text{.. (3.2)}$$

If the cutter rotates at N RPM and the feed/min is "f" "mm"

$$x = \frac{f}{N.n_t} \sin \phi \ldots \qquad [n_t = \text{no. of teeth in the cutter}]$$

Thus x_{max} will occur for $\phi = \phi_0$

$$\sin \phi_0 = \frac{2}{D} \sqrt{d(D-d)} \quad (\text{from } \triangle OB_1C)$$

$$x_{max} = \frac{f}{N.n_t} \sin \phi_0$$

$$= \frac{2f}{N.n_t.D} \sqrt{d(D-d)} \qquad \text{...(3.3)}$$

Hence $A_m = \frac{f.W}{D.N.n_t} \sqrt{d(D-d)}$ ...(3.3b)

or, $A_m \simeq \frac{f.W}{N.n_t} \sqrt{\frac{d}{D}}$ (neglecting d^2, which is small) (3.4)

In actual practice several teeth will be engaged simultaneously to obtain smooth cutting action for this purpose cutters are provided with helical teeth. In such cases the mean area of chip crossection is calculated from the volume of material removed in a given time.

Volume of material removed/min $= W \times d \times f$ mm³/min (3.5)

The volume is also equal to— $1000\, V \times A_m$. mm³/min ...(3.6)

W=width of cut mm.

where V=cutter speed m/min equating (3.5) and (3.6)

$$A_m = \frac{W.d.f.}{1000V}, \text{ mm}^2 \qquad \text{...(3.7)}$$

(*b*) **Face milling operation**

Figs. 3.3 (*a*) & (*b*) show the forms of chip-section produced during symmetrical and unsymmetrical milling with a face cutter when a single tooth is operating.

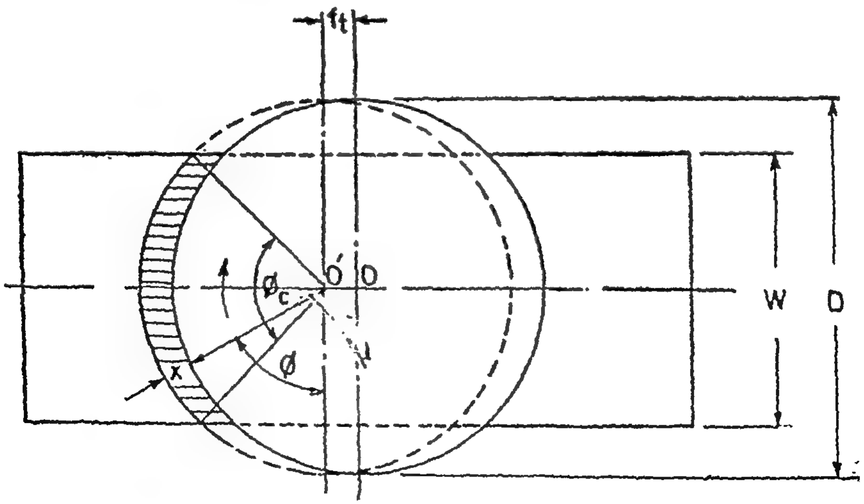


Fig. 3.3. (*a*) Symmetrical face milling

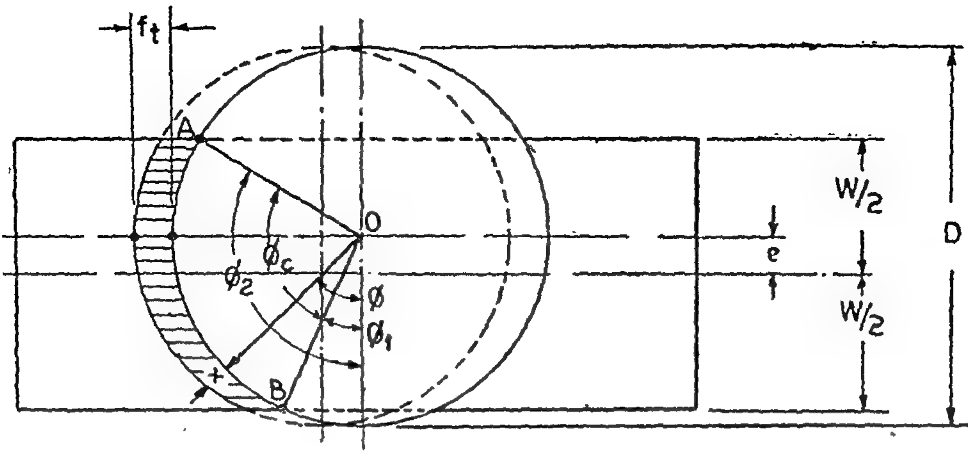


Fig. 3.3 (*b*) Unsymmetrical Faee_Milling.

From the fig. 3.3 (*b*)

$$\phi=\phi_2-\phi_1 \qquad \ldots\ldots(3.12)$$

$$\cos\phi_1=+\frac{W+2e}{D} \qquad \ldots\ldots(3.13)$$

$$\cos\phi_2=-\frac{W-2e}{D} \qquad \ldots\ldots(3.14)$$

For a face milling cutter with corner angle of 90°

The chip thickness at any instant is given by

$$x=f_t \sin\phi\ :$$

x_{min} occurs at $\phi=\phi_1$

$$x_{min}=f_t \sin\phi_1$$

x_{max} occurs at $\phi=90°$

$$x_{max}=f_t.$$

The mean chip thickness x_{mean} can be calculated by he equation.

$$\frac{D}{2}\int_{\phi_1}^{\phi_2} f_t \sin\phi \; d\phi=\frac{D}{2}\times\phi_c\times x_{mean} \qquad \ldots\ldots(3.15)$$

Solving, $x_{mean}=\dfrac{f_t\,[\cos\phi_2-\cos\phi_1]}{\phi_c}$ ......(3.16)

3.13 FORCES DEVELOPED IN MILLING

The total force required during milling is made up of the

(*i*) Force required for the plastic deformation of the layer of work material being removed.

(*ii*) Force required to overcome friction between the chip and face of the milling cutter and between the workpiece and relieved land of the cutter.

Fig. 3.4 gives a schematic representation of the forces developed by the cutter tooth during milling.

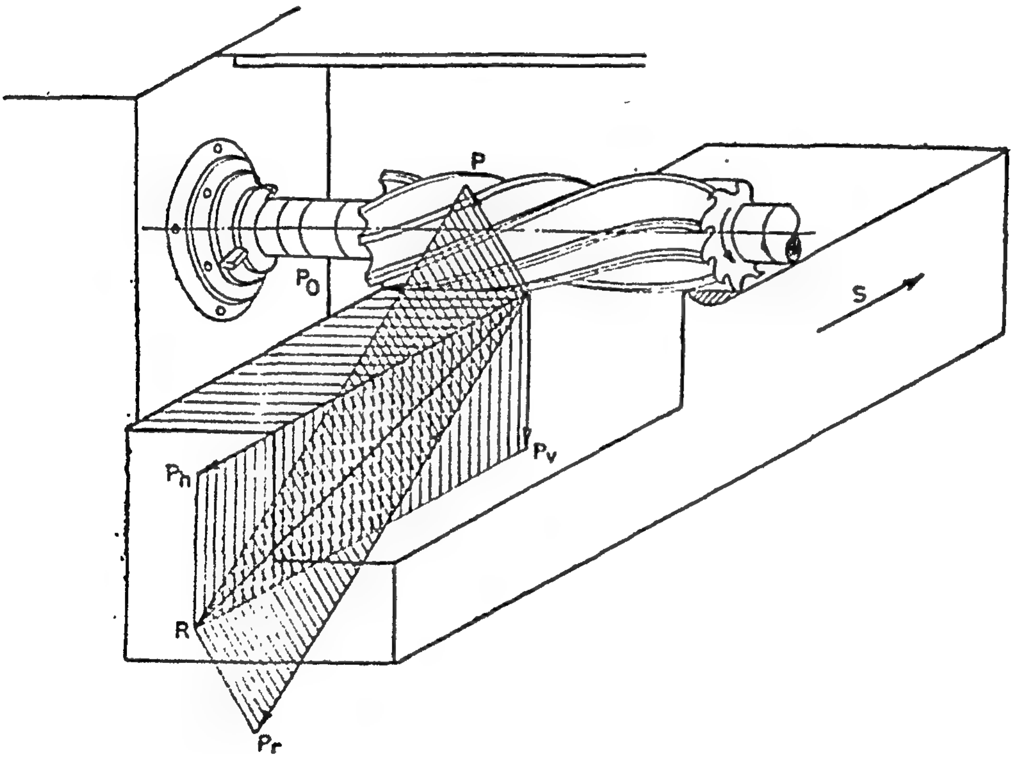


Fig. 3.4.

P=peri-pherical Component

P_r= horizontal Component

P_r=radial Component

P_v= Vertical Component

R= Resultant Force

Axial force : Milling Cutters with helical teeth also develop an axial component of the cutting force. The direction of this force would depend upon the hand of helix and the type of cutter.

3.14 SPECIFIC CUTTING PRESSURE

The specific cutting pressure (σ) is the cutting force in kilograms per squre millimeter of chip-cross-section being removed.

$$\sigma = \frac{P}{A_n} \text{kg/mm}^2 \qquad \ldots 3.17$$

P=peripherial component of cutting force kg.

A_m=Mean chip area of crossection mm^2.

or $P = \sigma\ A_m$ 3.18

TABLE III

Specific Cutting Pressure (σ) in Milling

Max chip thickness mm.	Specific Cutting Pressure kg/mm²					
	Steel			Cast Iron		
	Soft	medium	hard	Soft	medium	hard
0.02	316—420	526—635	740—850	210	305	420
0.04	267—365	435—535	620—710	163	235	426
0.06	240—320	400—480	560—640	142	205	285
0.08	226—302	376—452	530—604	129	186	259
0.10	214—284	358—428	500—572	122	175	244

The value of "σ" depends upon the work-material hardness and the chip-crossection. Table III, gives the values of specific cutting pressure for various materials in milling depending upon the maximum chip thickness A_{max}. A knowledge of the mean-chip thickness does not give any idea about the maximum value of P which is important from design point of view. It can be usually be assumed that $P_{max}=1.2-1.8$ times P,

3.15 POWER REQUIRED IN MILLING

The work done in unit time during milling is given by.

$$=PV \quad \text{kg m/min} \qquad \ldots\ldots 3.19$$

$$\text{The cutting H.P.}=\frac{PV}{75\times 60} \text{ H.P. (metric)} \qquad \ldots\ldots 3.20$$

V=cutting speed in m/min.

P, the peripherial component of cutting force (kg) during milling under the given conditions can be calculated from equation (3.18) and the value of "σ" for the given material can be obtained from the table III

Torque on the cuttter is given by $P\times\frac{D}{2}$ kg mm. where

D=diameter of the cutter. (mm)

3.16 Example

Determine the net power required for the following milling operation.

Work material	*Soft Steel*
Cutter diameter (D)	*75 mm*
No. of teeth (n_t)	...*8*
Cutting Speed (v)	...*25 mm/min*
Feed velocity (f)	...*75 mm/min.*
Width of cut (w)	...*100 mm.*
Depth of cut (d)	...*5 mm.*

The maximum chip thickness is given by eqn. (3.3 *a*)

$$x_{max}=\frac{2f}{Nn_tD}\sqrt{d(D-d)}$$

N the r.p.m. of the cutter can be calculated from the data supplied.

$$N=\frac{25\times1000}{\pi\times75}=106 \text{ r.p.m.}$$

$$x_{max}=\frac{2\times75}{106\times8\times65}\sqrt{5\times70}$$

$$=0.0442 \text{ mm.}$$

Taking an average value of the specific cutting pressure corresponding to the maximum chip thickness of 0 0442 mm. from the table III as 300 kg/mm².

The peripherial force=P=300×A_m.

$$\text{where } A_m=\frac{w.d.f.}{1000\ V}, \text{ mm}^2 \text{ (from eqn. 3.5)}$$

$$=\frac{100\times5\times75}{1006\times25}=1.5 \text{ mm}^2.$$

The peripherial force, P=300×1.5=450 kg.

$$\text{The H.P. required} \quad =\frac{450\times25}{75\times60}=2.5$$

In the above problem if the depth of cut "*d*" is reduced to 2.5 mm. and the feed velocity is increased to 150 mm/min the rate of metal removal will remain constant. However x_{max} in the case would be given by

$$x_{max}=\frac{2\times150}{106\times8\times75}\sqrt{2.5(75-2.5)}$$

$$=0.0636$$

Specific cutting pressure "σ" corresponding to this value of x_{max} can be taken to be 270 hg/mm². (Table III)

The peripherial cutting force would now be

$$P=270\times A_m \text{ kg.}$$

A_m will remain constant as the rate of metal removal is unchanged.

hence $P = 270 \times e.5$ kg.
$= 405.0$ kg.

The H.P. required$= \dfrac{405 \times 25}{75 \times 60} = 2.26$

Therefore we see that for the same rate of metal removal reducing the depth of cut and increasing the feed rate is advantageous as from the pywer consumption point of view.

3.2 FORCES AND TORQUE IN DRILLING

Drilling consists of producing holes in work-pieces by rotary and axial movement of the tool or the work piece.

3.2.1. Forces and Torque in Drilling

Like any other metal cutting tool, when in operation the drill is subjected to a twisting couple (M) and an axial thrust "T" (Fig. 3.5) The quantities which influence the torque and thrust acting on the drill are

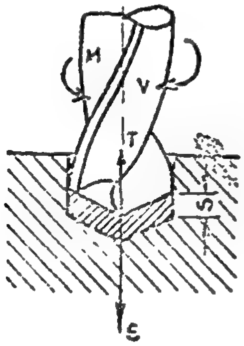


Fig. 3.5

(*i*) work material and its structure
(*ii*) drill diameter (d)
(*iii*) helix angle (θ)
(*iv*) length of chisel edge $(c) = \dfrac{\text{web thickness}}{\text{cosine (chieseledge angle)}}$
(*v*) point angle (2ρ)
(*vi*) number of cutting edge (n)
(*vii*) feed, mm/rev.
(*viii*) depth of cut (=drill diameter/2)
(*ix*) cutting fluid
(*x*) drill sharpness.

The torque acting on the drill is due to tha following action.

(1) Cutting along the lips of the drill

(2) Cutting at the chisel edge

and (3) Extrusion at the chisel edge

For torque calculation, the effect of extrusion at chiesel edge would be small hence negligible. However, the extrusion effect will mainly be felt on the thrust acting on the drill. The torque acting on the drill is determined by the formula.

$$M = c_1 \, d^{1.9} f^{0.8} \text{ (kg. mm)} \qquad \ldots (3.21)$$

Where c_1 is a constant, its value depending upon the cutting conditions.

for Carbon Steel $C_1 = 33.8$

for Cast Iron BHN 190 $C_1 = 23.3$

The thrust acting on the drill is also due to the three factors mentioned above. The thrust on the drill is given by the relationship

$$T = C_2 d f^{0.7} \text{ (kg)} \qquad \ldots (3.22)$$

Where C_2 is a constant, its value given by the drilling conditions.

$C_2 = 84.7$ for Carbon Steels

$C_2 = 60.5$ for Cast Irons.

3.3 POWER REQUIREMENTS IN BROACHING

The pull or the cutting force acting on the broach whilst broaching round holes in steel may be approximated by the formula.

$$T = C_3 f^{0.85} dz \text{ kg.}$$

C_3 is a constant, value depending upon the material to be broached.

f—feed per tooth, mm

d—broach diameter, mm

Z—number of broach teeth cutting at a time.

The power required for broaching is determined by the formula

$$P = \frac{TV}{60 \times 120} \text{ kw.}$$

V=broaching speed m/min.

The permissible cutting speed "V" during broaching can be determined by the equation.

$$V = \frac{c}{T^x f^y} k \text{ (m/min)}$$

C—is a constant, depending upon the working conditions.
T=broach life. mins

K—coefficient, depending upon the broach material typical Values for broaching round holes in steel are

C	T	x	y	k	BH. N. of Steel beiug broached
12	100 mid	0.62	0.62	1—1.55	160—180

The Cutting Speed employed for broaching often varies between 1—18 m/msn.

QUIZ

1. Differentiate between up and down milling operations. State in reference to chips forined the limitations in each case.

2. Show that the mean chip thickness cut during plain milling is given by

$$Am \simeq \frac{fW}{Nn_t} \sqrt{\frac{d}{D}}$$

State the assumptions made.

3. State the important parameters which influence the torque and thrust in drillng. Describe the cutting action of a drill.

4. Describe how will you, select the cutting speed for broaching ? Outline a method for calculating the power required for a broaching operation.

5. Draw a diagram showing the cutting action of a milling cutter and indicate thereon the forces acting over the cutter tooth.

CHAPTER 4

THEORY OF MACHINABILITY

4 01 DEFINITION

Considerable effort has been made to define the term machinability of metals by many investigators like Ernst, Boston, Leyensetter Woldman and Gibbons, Takeyama and others. However, the definition put forward by Woldman and Gibbons that—'the most machinable metal is one which will permit the fastest removal of the largest amount of material per grind of tool (without resharpening of the tools) with satisfactory finish' sounds pretty satisfactory.

4·01 EVALUATION OF MACHINABILITY

In earlier days attempts were made to define 'machinability' in terms of ordinary mechanical properties. In 1928, first time a simple law of machinability was proposed by E. G. Herbert—'the measure of machinability is the hardness of chip'. But while testing some ferrous and non-ferrous alloys Boston found that the hardness data were misleading as a measure of machinability. Boston and Kessener developed penetration tests with the twist drill for a rapid determination of machinability. The assumption that the drill made a hole with a depth proportional to the machining properties of the metal tested was not fool-proof. The same holds good for the sawing tests used by A.S. Kenneford. Criterion of machinability characteristics of metal was the time required to saw the test bar. Here, the objection was high friction (which is a varying factor) at the saw blade on account of which cutting time could not be taken as a true measure of machinability.

In 1943, A.O. Schmidt using the first law of thermodynamics, developed calorimetric method to evaluate machinability of light metals and alloys *viz.* aluminium, megnesium and their alloys.

It is thus very clear that there is no direct method of determining the ease and difficulty of removing metal and therefore, use of indirect methods have always been made to evaluate machinability of metal. In this direction Boston has suggested following ways of evaluating machinability :

(*a*) Long tool-life for a given cutting speed or a high cutting speed for a specific tool life.

(*b*) High surface quality of the machined surface.

(*c*) Well broken chips for easier disposal.

(*d*) Low power consumption in removing a given quantity of material.

(*e*) Uniformity in dimensional accuracy of a successive parts.

(*f*) Maximum metal removal per tool grind.

(*g*) Removal of each unit of metal at the lower overall cost.

However, the literature reveals that the most important factors which are these days considered for evaluation of machinability are :

1. **Tool Life.**
2. **Types of Chips & Shear Angle.**
3. **Cutting Forces & Power Consumption.**
4. **Surface Finish.**

The relative importance of these four items depends upon the kind of machining operations. This has been stated in a tabulated form as below :

TABLE IV

Order	Rough Operation	Finishing Operation	Automatic M/c Tool Operation
1.	Tool Life.	Surface Finish	Types of Chips
2.	Power Consumption	Types of Chips	Surface Finish
3.	Types of Chips	Tool Life	Tool Life
4.	Surface Finish.	Power Consumption.	Power Consumption

4·02 TOOL LIFE

During machining, the cutting edge of the tool gradually wears out and it does not perform satisfactorily. When the wear reaches a certain stage it is said that the tool has lost its utility and its life is over. It must be reground or replaced by a new tool if machining is to be continued. The period during which a tool cuts satisfactorily is called tool life. Thus, the tool life may be defined as a period between two consecutive tool resharpenings or replacements. Usually it is expressed in terms of time unit, particularly in minutes. Also, it has been expressed in terms of volume of metal cut per tool regrind. Two other definitions are based on number of components produced per tool regrind and the cutting speed for a desired time of tool failure.

Tool life is a valuable measure of machinability in preference to other criteria because it is a factor of direct importance to shops. Tool preparation cost and down time for tool changing are big factors in production machining.

At the begining of this century F. W. Taylor developed a relationship between tool life and cutting speed based upon his exhaustive experimental work. This classical equation is

$$VT^n = C$$

Where V = cutting speed, *fpm* (or *mpm*)

T = Tool Life, minutes

n = an exponent

C = Constant depending upon cutting conditions and work material.

The values of V and T when plotted on a log-log graph give a straight line (fig. 4·01) On carefully observing this graph it can be interpretted that it is never desirable to machine at very high and very low cutting speeds. Machining at higher cutting speeds leads to much earlier failure of the tool whereas machining at lower speeds gives lower production rate.

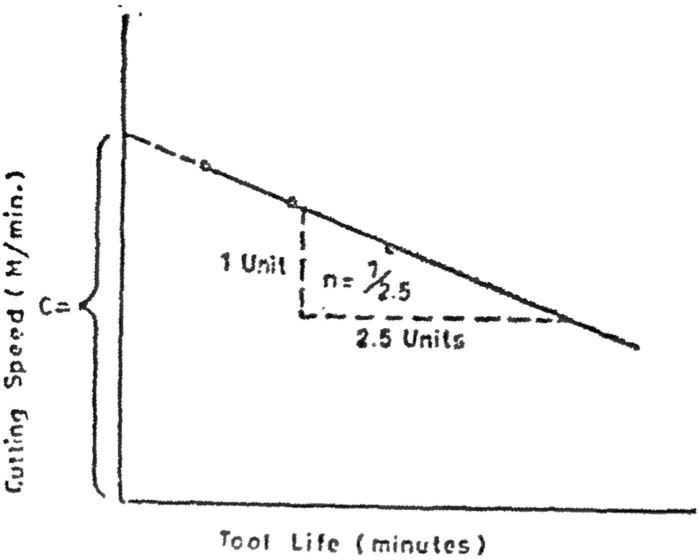


Fig. 4·01 A Tool Life Plot

4·021 Tool Life Plots

The tool life line is obtained by performing the cutting tests at higher cutting speeds. preferable having valves 100 m/min. and above. The corresponding time of tool failure (predetermined flank wear or crater wear which ever occurs first) for each cutting speed is recorded. These points are plotted on a log-log graph when the plot would be a linear line. Since a line can be drawn with two points, let the tool life plot be drawn with three points so as to have a better average plot. Large number of points are not necessary as cutting tests for large number of points take larger time and consume quite a large amount of material.

The tool life plot can be used for two things. Firstly, it can be used to determine the value of exponent (*n*) and constant (C) of tool life equation. Secondly, it can be used to predict the values of tool life at other cutting speeds. The slope of the tool-plot is the value *n* and the intercept of the Y-axis, when the plot is extended backwards to meet Y-axis, is the value C, (fig. 4·01) the tool life is one minute.

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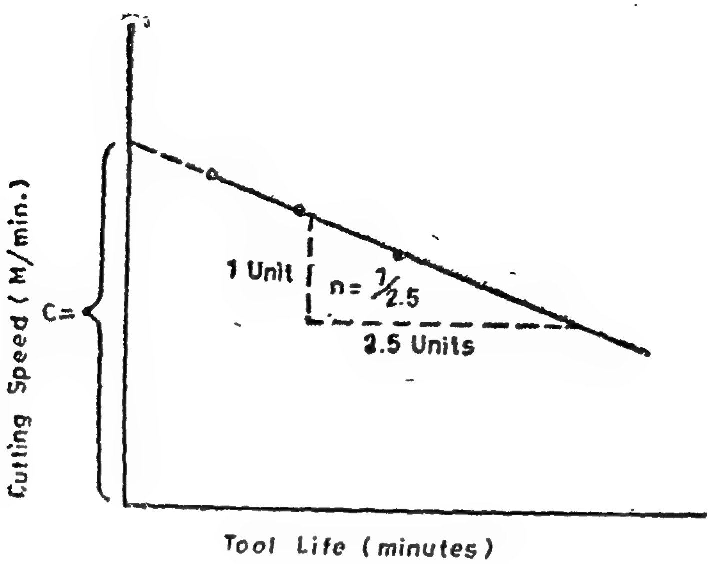

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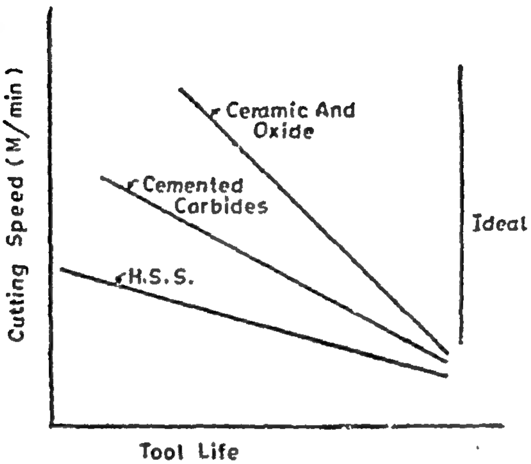
The slope of the tool life plots remains constant for a particular combination of tool-workmaterial. However, the plots may be higher or lower depending upon the cutting conditions *i.e.* feed and coolant.



Fg. 4·02 Tool Life Plots for Various Cutting Tool Materials

The tool life plots in terms of metal removed per cutting edge for different tool materials are shown in fig. 4·02. It can be observed that high speed steel is very sensitive to change in speed. As we move from high speed steel towards oxides this sensitivity tends to reduce and we can imagine that an ideal tool material would be one which does not show any change with any little change in the cutting speed. The hypothetical line drawn in fig. 4·02 represents this ideal material.

The tool life of a tool is said to be over if

(*i*) The tool has failed.

(*ii*) Chatter shows up in machining.

(*iii*) Poor surface finish is obtained.

(*iv*) Sudden increase in power and cutting forces occur.

(*v*) Overheating and fuming due to heat of friction takes place, and

(*vi*) Dimensional unstability is observed.

The most important factor in the above list is the tool failure.

4·022 Types of Tool Failure :

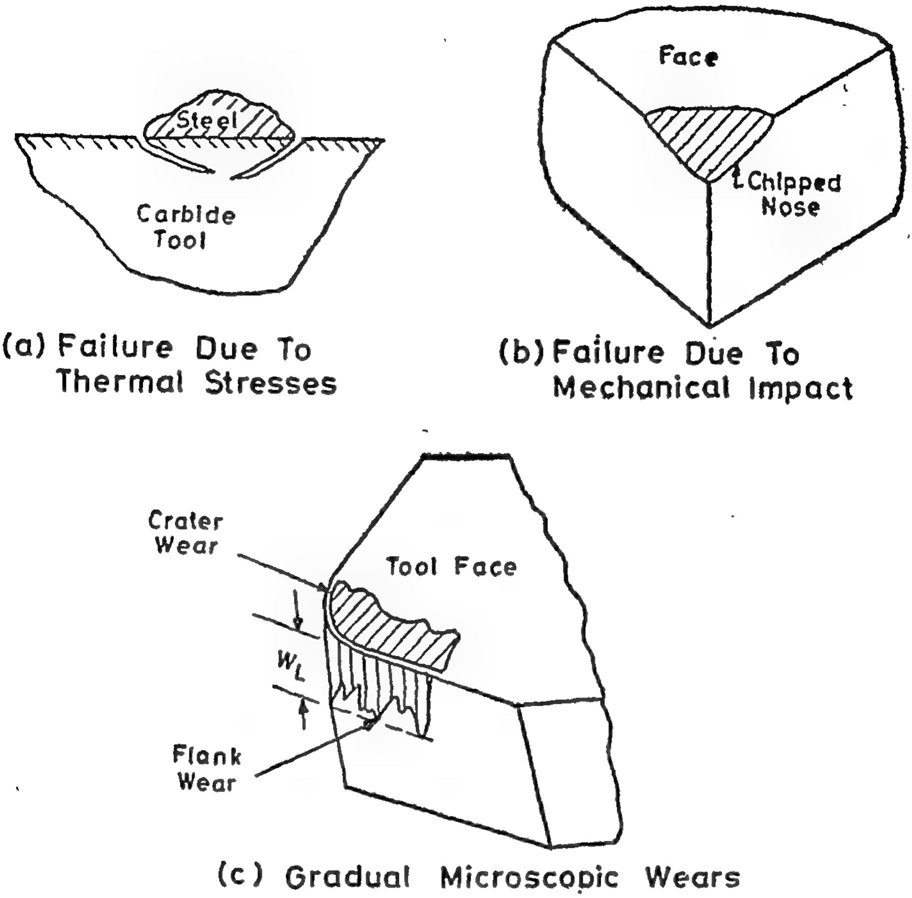


Fig. 4·03 Types of Tool Failure

(*a*) Temperature Failure

(*i*) plastic deformation of cutting edge due to high temperature

(*ii*) Cracking at the cutting edge due to thermal stresses

(*b*) Chipping of the edge or fracture due to mechanical impact

(*c*) Gradual microscopic wear

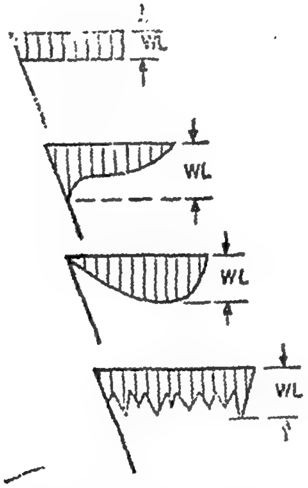
(*i*) Flank wear

(*ii*) Crater Wear

All types of tool failures except that by gradual wear, in theory atleast can be prevented by talking suitable precautions. They are so

uncertain that they may or may not occur during machining. But gradual wear is unpreventable, since it occurs continuously from the commencement of machining. The limit of of this type of wear is solely decided by the economic consideration of the operation. Thus, for all practical evaluation of tool life, investigators have been using flank wear or crater wear or both as the basis.

4·023 Flank Wear :



Some Patterns Of Flank Wear

Fig. 4·04

Flank wear occurs mainly on the nose part, front relief face and side relief face. It is due to the abrasive action of hard microconstituents including debris from built up edge as the work material rubs the worksurface. This wear primarily depends upon the relative hardness of the work and tool materials at the operating temperature, the amount and distribution of hard constituents in the work material and the degree of strain hardening in the chip. Some of the patterns of flank wear encountered during machining have been shown in fig. (4·04)

The flank wear height (W_t, sometimes h_f is also used) is time dependent. On plotting (h_f) against time a non-linear relationship is obtained fig. (4·05). This kind of tool wear could be treated to be formed of three parts. The part 0 1 exists for a very very short

duration and it represents rapid rate of wear. The sharp edge is quickly worn away. Between 1—2, the curve is relatively linear. This wear rate exists for a long time depending upon the cutting conditions, tool geometry and material of workpiece and tool. Beyond 2 it is total failure of the tool and the wear occurs so rapidly that hardly any control is possible. Most of the tools once they enter in the zone are uneconomical to ground and the tolerance of the workpiece is also lost and defective parts are generated.

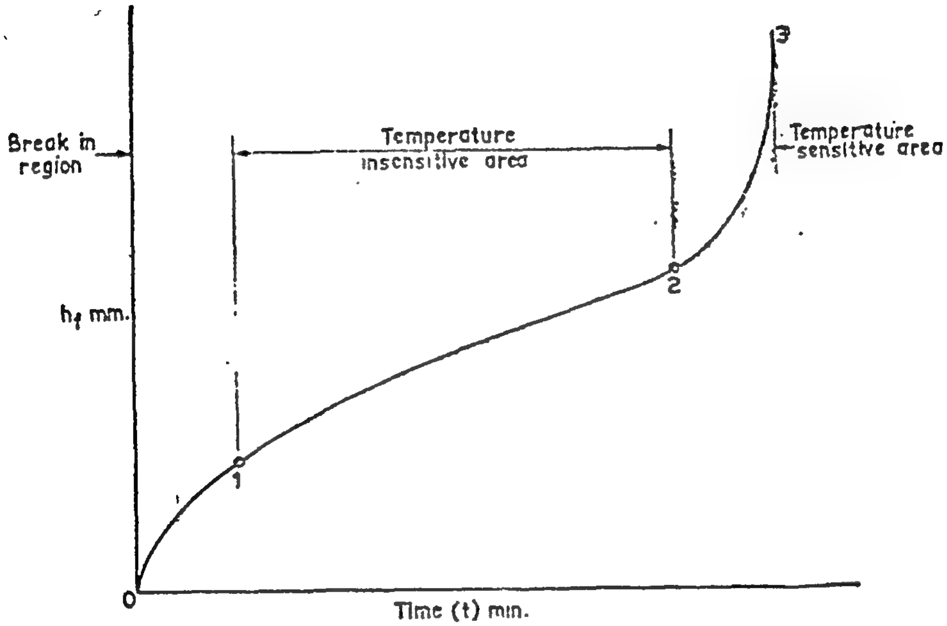


Fig. 4·05 Typical Flank Wear Rate Curve

The size of the flankwear is measured by a low magnification (×20) microscope having linear graduation on the eye piece. Maximum length of the wearland (W_f or h_f) is measured for all experimental purposes.

It is often stated that cutting tools ought to be reground when W_f reaches some definite value of 0·5 mm or so. If regrinding is not to be carried out at this stage serious breakdown of tool may occur. The reason for this appears to be associated with the formation of thermal cracks and plastic deformation. In this regard St. Clair suggests an useful tip to the designers of the cutting tools that the high speed tools should be withdrawn when 75% of its useful life is over and similarly, the carbide should be withdrawn when 60% of its useful life is over.

4·024 Crater Wear

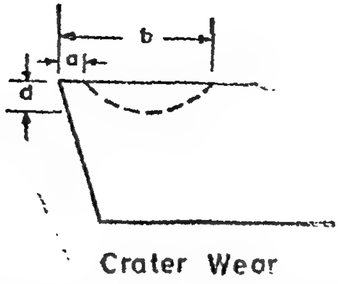


Fig. 4·06 Crater wear geometry of a tool

Crater wear occurs on the face of the cutting tool at a short distance 'a' from the cutting edge. This kind of wear is encountered usually while machining ductile materials like steel and its alloys. It leads to the weakening of tool, increase in cutting temprature, friction and cutting forces. The continuous growth of crater will ultimately result into total failure of the tool.

The explanation for crater formation has recently assumed very complex nature due to the theories developed by Dawhil, Loladze Trigger and Opitz. The most simple explanation is due to Trent who stated that the work material alloys with tool material due to extremely high temperature developed at the cutting edge. Later the alloyed layer being carried away with the chip due to high pressure at the tool face." This sort of alloying phenonenon where the metals have not reached the melting point and yet alloyed, is known as "diffusion of metal." The reason for the alloying is the increased activity of the molecules on the nascent surfaces of the chip and tool at high temperature. This aspect has been extensively investigated by Loladze and Opitz but still any acceptable theory could not be evolved. Opitz has concluded that a tool wears out due to diffusion, abrasion, oxidation and adhesion (fig. 4·07) and that temperature plays a very important role.

The geometry of crater wear has been shown in the fig. (4·06) where $(b-a)$ is width of crater and d is depth of crater. The tool life due to crater wear can be determined by fixing the ratio

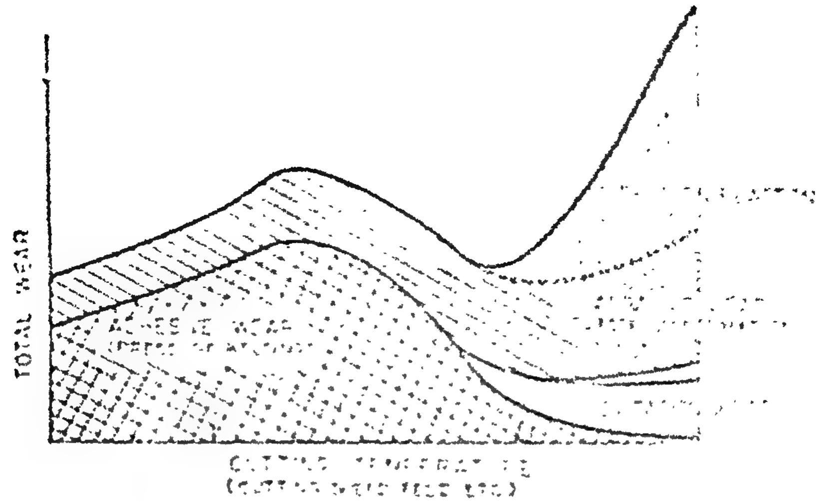


Fig. 4·07 Effect of temperature on the kinds of tool wear (Opitz)

$$X = \frac{d}{\left(\frac{b-a}{2}\right) + a}$$

$$= \frac{2\,d}{b+a}$$

The values of X for carbide tools and H.S.S. tool have be experimentally determined to be 0·4 and 0·6 respectively.

Measurement of the amount of crater is not as simple as that of the flankwear. This is the main reason to express the tool life in the term of flankwear. Different techniques have been used by the investigators while performing laboratory tests on crater wear. One of the methods as used by Trigger and Chao, is the measurement of the depth of crater on a sectioned tool. Several readings at different sections have to be taken to define the crater contour. Recently, the use of radio-active isotopes have also been used by Merchant and Krabacher for quick determination of crater wear.

4.025 Factors Affecting Tool Life :

A. Tool Geometry—larger side rake angle produces chipping and smaller rake angle generate greater heat or an excessive wear and deformation in tool.

Little effect is seen with change in back rake angle between −5° to +6° in case of flank wear. At high rake angles [illegible] there tends to be an optimum rake angle for maximum tool life.

chip is thick. Thus the force required to remove the layer of metal of thickness t'_2 is always higher. If the angle is large (upto 45°), the path of shear is short, the chip is thin and force required to remove the layer of metal of thickness t''_2 is less. A metal requiring less force for cutting can obviously be classed as easily machinable metal Thus, the shear angle ϕ is an important geometrical quantity in the cutting of metal which can be used as a criterion for machinability of metals.

The role of shear angle and chip-tool contact area (or length) on machinability has been differently explained by Chao and Trigger on the basis of their work on thermophysical aspects of metal machining. They have concluded that temperature at tool-chip interface is inter-dependent on the inclination of shear plane or size of shear zone and length of chip-tool contact. The temperature at interface is a sum of rise due to frictional sliding and deformation at shear zone. Thus, a better machinable metal is one which gives a larger shear angle (*i.e.*, smaller shear zone) and lower chip tool contact are a (i.*e*. smaller tool-face friction force) so that heat generated is less and the tool life is more. Both these parameter have successfully been used by Okushima & Iwata, and Singh & Sharan while studying the machinability of leaded steels and alloyed cast irons respectively.

4·04 CUTTING FORCES & POWER CONSUMPTION

Considerable light can be thrown upon the machinability of metal from cutting forces acting at the cutting edge while machining metal. A metal possessing better machinability should show less values for cutting force. This criteria is of prime importance in roughing operation when the magnitude of cutting force is already high. If a material is less machinable the magnitude of force is considerably large which may be detrimental to cutting edge and the machine tool.

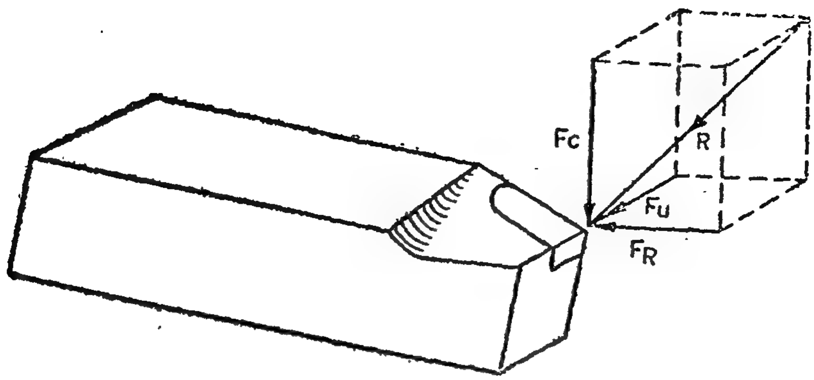


Fig. 4·10 Force Components on a single point tool

From the main component of the cutting by force (F_c) the net power at the cutting edge can be evaluated

$$H=\frac{F_c \times V}{60 \times 75}$$

It can be used as another criteria for machinability rating. Usually specific cutting energy (E) is used for establishing the machinability which has been defined as the power required to remove unit volume of metal per minute. Its value depends upon microstructure, ductility, strength, coefficient of friction and work hardening characteristics of the metal.

The cutting force at the tool edge can be measured directly with a suitable force dynamometer. It can also be computed if the cutting parameters and work material properties are known by using Merchant's relationship or Lee & Shaffer formula

$$F_c=S_s\ s.t\ \frac{\text{Cos}\left[\frac{\pi}{2}-2\phi\right]}{\text{Sin}\ \phi\ \cos\left[\frac{\pi}{2}-\phi\right]} \quad \text{(Due to Merchant)}$$

$$F_c=\tau_s\ s.t\ \frac{\text{Cos}\ (\beta-a)}{\text{Sin}\ \phi\ \cos\ (\phi+\beta-a)} \quad \text{(Due to Lee \& Shaffer)}$$

$$=\tau_s.\ s.t.\ [1+\tan\phi]$$

Where S_s and τ_s are static and dynamic shear stresses.

A wattmeter should never be used because it shows the behaviour at the motor and not at the tool.

4·05 SURFACE FINISH

Surface finish is yet another factor used for rating machinability of metals. A poor surface finish, in general, speaks for poor machinability of a metal because to obtain fine finish afterwards means an increase in the cost of product.

In machining metals there are two reasons for surface roughness, (*a*) the feed marks or ridges left by cutting tools, and (*b*) fragments of BUE on the machined surface. The cutter vibrations

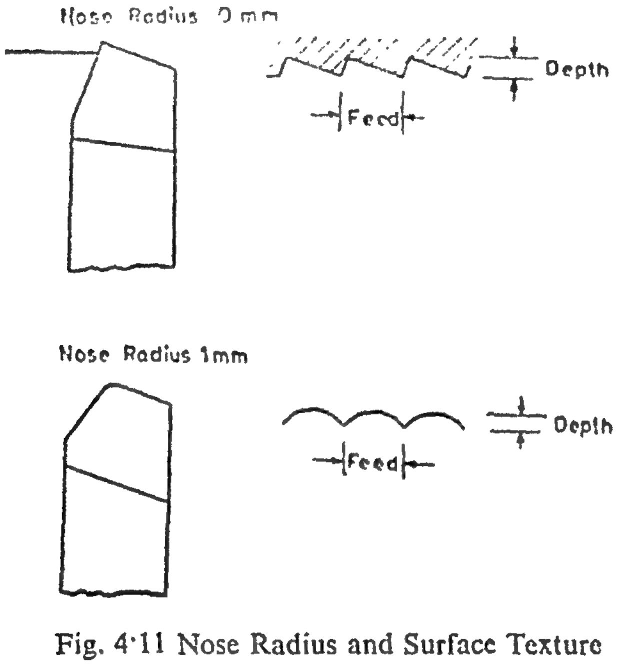


Fig. 4·11 Nose Radius and Surface Texture

and roughness of cutting edge are the other two causes but of secondary importance.

An ideal state of a machined surface is a profile resembling the contour of the shape of the tool repeatedly produced in the case of turning. The pitch of grove being equal to the feed per revolution. In other words, a single point tool generates helix thread whose pitch is determined by the feed per revolution fig. 4·11. The following relation has been established :

$$H\ max = S^2/8r$$

H max—Height of feed marks in 0·001 *mm*

S—feed per revolution, *mm* per rev.

r—nose radius, *mm*.

The above formula is valid as far as end cutting edge angle $\geqslant \sin^{-1} \frac{S}{2r}$.

The effect of various factors on the surface finish can be summarised as below :

1. Increase in cutting speed improves surface finish.
2. Increase in feed rate deteriorates surface finish.
3. Increase in depth of cut, deteriorates surface finish.
4. Increase in true rake angle improves surface finish.
5. Increase in nose radius improves surface finish.

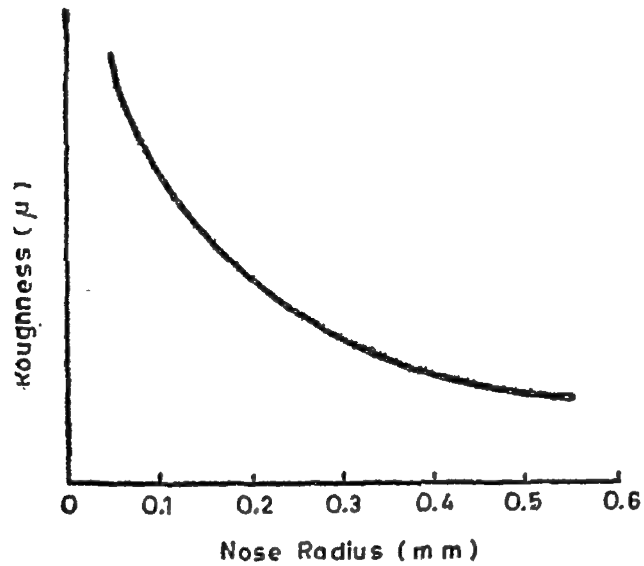


Fig. 4·12 Effect of nose radius on surface finish

Nose Radius and surface Finish : By providing large radius at the nose of the tool two advantages are added. Firstly, it ensures high strength at the weakest zone of the tool (*i.e.* nose) and secondly, considerable improvement in the surface finish is achieved.

It would be enrroneous to derive from this fact that the nose radius can be increased to an indefinite limit. Larger nose radii

upon the type of the tool used and number of cutting edges that it had. Thus for a solid tool or a brazed bit H.S.S. and carbide tool the cost per edge is obtained by the relation

$$Z = \frac{\text{Tool Cost}}{\text{No. of regrinding} + 1}$$

and for throw away bit tool, it is obtained from

$$Z = \frac{\text{Cost of tool bit}}{\text{No of cutting edges}} + \frac{\text{Tool holder depreciation}}{\text{per cutting edge}}$$

The tooling cost is directly dependent upon the speed at which machining is done.

Analysis for Optinum Cutting Speed :

Let Z_1—Direct labour and overhead rate (Rs.)

Z_2—Tool cost per grind including depreication (Rs.)

D—Work diameter. mm.

L—Length of the work, mm.

V—Cutting speed, m/min.

T—Tool life, min.

F—Feed, mm/rev.

t_m - time to machine per piece, min.

1. Non-productive Cost per piece :

$= Z_1 \times (\text{non-productive time/pc.}) = \text{constant}$

2. Machining Cost

$= Z_1 \times \text{machining time}$

$$= Z_1 \times \frac{\pi DL}{1000\, Vf}$$

3. Tool Changing cost/piece

$= Z_1 \times (\text{time for tool failure per pc.} \times TCT)$

$$= Z_1 \times TCT \times \frac{t_m}{T}$$

$$= Z_1 \times \frac{\pi DL}{1000\, Vf} (V/C)^n \times TCT \text{ (Assuming that } VT^n = C)$$

4. Tool regrinding cost/piece

$=Z_2 \times$ time of tool failure per pc.

$$=Z_2 \times \frac{\pi DL}{1000\, Vf}(V/C)^{\frac{1}{n}}$$

Summing 1, 2, 3 & 4, we have

Total cost per pc. C_p

$$=\text{Constant}+Z_1 \frac{\pi DL}{1000\, Vf} + Z_1 \frac{\pi DL}{1000\, Vf} (V/C)^n TCT$$

$$+Z_2 \frac{\pi DL}{1000\, Vf} (V/C)^{1/n}$$

For the total cost per pc. to be minimum, the first derivative of C_p with respect to V should be equated to zero and the second derivative should bo positive.

$$\frac{d(C_p)}{dv} = O - Z_1 \frac{\pi DL}{1000\, Vf}(V^{-2}) + Z_1 \frac{\pi DL}{1000\, Vf}\left(\frac{1}{n}-1\right) \times \frac{V^{\frac{1}{n}-2}}{C^{\frac{1}{n}}} TCT$$

$$+Z_2 \frac{\pi DL}{1000 f}\left(\frac{1}{n}-1\right)\frac{V^{\left(\frac{1}{n}-2\right)}}{C^{\frac{1}{n}}} = 0$$

Or $\quad Z_1 V^{-2} = \left(\frac{1}{n}-1\right)\frac{1}{C^{\frac{1}{n}}} V^{\left(\frac{1}{n}-2\right)}(Z_1 . TCT + Z_2)$

$$\frac{V^{-2}}{V^{\left(\frac{1}{n}-2\right)}} = \left(\frac{1}{n}-1\right)\frac{1}{C^{\frac{1}{n}}}\left(TCT+\frac{Z_2}{Z_1}\right)$$

$$V^{\frac{1}{n}} = \frac{C^{\frac{1}{n}}}{\left(\frac{1}{n}-1\right)\left(TCT+\frac{Z_2}{Z_1}\right)}$$

Hence the cutting speed for minimum cost comes to be

$$V_{min} = \frac{C}{\left[\left(\frac{1}{n}-1\right)\left(TCT+\frac{Z_2}{Z_1}\right)\right]^n} \quad \text{where} \quad \frac{1}{n}>1$$

$$= C\left[\frac{n}{1-n}\right]^n \left[\frac{Z_1}{Z_1 TCT+Z_2}\right]^n$$

The corresponding expression for critical tool life can be worked out on the basis of Taylor's equation.

$$VT^n=C$$

$$V = \frac{C}{T^n}$$

$$T \text{ for min. cost}=\left(\frac{1}{n}-1\right)\left(TCT+\frac{Z_2}{Z_1}\right)$$

The ideal cutting speed is usually that which reduces the total cost of machining to give a minimum cost per piece. But there are cases where cost is secondary to the more important objective of maximum production, and the cutting rate becomes faster than that which produces minimum cost per piece. While the faster machining rate shortens tool life, time per piece is reduced and many other cost factors, normally not considered, such as direct and indirect labour overhead, plant burden and fringe benefit costs are reduced.

$$\text{Thus } V \text{ for max. Prod.}=\frac{C}{\left[\left(\frac{1}{n}-1\right)TCT\right]^n}$$

$$T \text{ for max. Profit} =\left[\frac{1}{n}-1\right]TCT.$$

From the above results it is possible to establish a range which should always give high machining efficiency. fig. 4·15 represents graphically the effect of cutting speed on the total cost/pc., total time per pc. and pieces per unit of time (production rate). Join the lowest point of total cost per pc. curve and highest point of the production rate curve. The area below the line joining these points determine a range which gives a compromise between the minimum cost and maximum production. This range is called as Hi-E Range (High Efficiency Range) and the

concept of Hi-E was developed at G.E. (USA) by Dr. Gilbert's group.

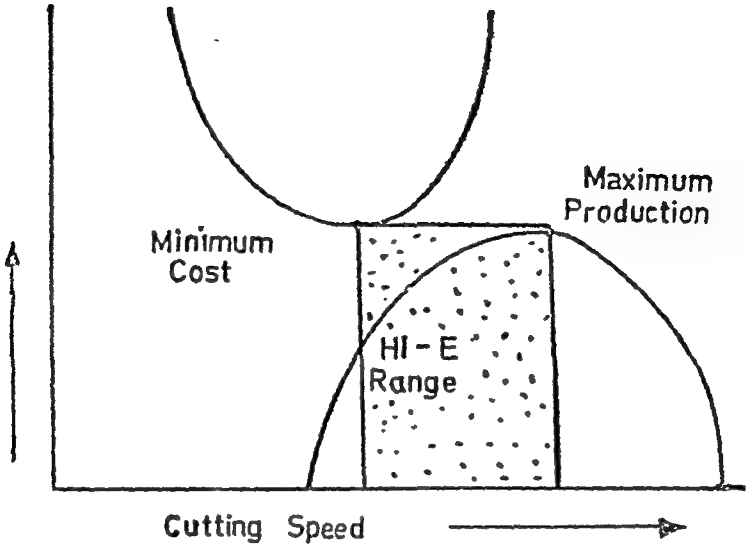


Fig. 4·15 High Efficiency Range

The Hi-E range may be wide or narrow depending on job conditions. If tool cost is relatively low for a given job minimum production values may be with in 5% or 10% of one another. Where tool cost is high the end points of the range could have 30% or 40% differential. Other factors that must be considered are machine capacity, ability of operator to keep up with the equipment and sometimes the operation itself.

Examples 1. *In a tool wear test with a high steel speed steel cutting tool, the following values of tool life were obtained—*

Tool life	*Cutting speed*
30 min	*25·0 m/min*
1·5 min	*70·0*

Calculate the values of n and C of Taylor's equation

Solution :

$$VT^n = C$$

$\therefore$ $\log V + n \log T = \log C$

(*i*) When $T = 30$ and $V = 25$

$$\log 25 + n \log 30 = \log C$$

CHAPTER 5

CUTTING TOOL MATERIALS

The development of newer types of tool materials is always associated with the demand for higher rate of machining and better tool design. Before 1870, most of the industrialised countries were only familiar with high-carbon steel forged-tools containing about 1% carbon and 0.2% Mn. This material had low hardness at elevated temperatures and therefore, very low speed machining was possible. Robert Mushet introduced another type of steel containing 8% carbon, 5.5% tungsten, 1 6% Mn and 0.4% Cr. which could retain hardness even at elevated temperature, making it possible to machine the steel at relatively higher speeds. By this time, it was realised that for faster machining the tool material should have three basic properties—*Wear Resistance*, *Red Hardness* and *Toughness*.

Based on the above three requirements, in 1900, F.W. Taylor and M. White developed a steel with which they could machine steel at a relatively higher speed (60 fpm) and they named it as "High Speed Steel." By 1926, the so-called super-high speed steel was introduced to the industries. At this very time, Germans introduced another wonderful cutting tool material, the tungsten carbide. It was not until 1941 when the stress of war-time was felt in commonwealth and the U.S.A that a series of investigations in the field of development and applications of carbides were undertaken. When other countries were working on tungsten carbides, German were struggling hard to develop yet another type of tool material due to accute shortage of tungsten and cobalt which led to the development of ceramic (oxide) cutting tool material.

5.01. FACTORS TO THE DEVELOPMENT OF NEWER TOOL MATERIALS :

1. *Economic competition.*
2. *Shortages of rawmaterials at critical times,*
3. *Need to machine materials of higher strength and,*
4. *Military necessity.*

5.02. REQUIREMENTS OF A TOOL MATERIAL :

The most essential requirements for all types of cutting tool materials are as described below :

1. *Red Hardness* : It is the ability of the material by virtue of which it retains hardness while working at elevated temperature. The term red-hardness originated with the earlier performance of high speed when it was noticed that the cutting tool could cut successfully even though the area around the cutting edge was full red in colour. The elements that contribute to red hardness are chromium, molybedenum, tungsten and vandium, all of which form and stable carbides. The red-hardness of the diamond is by far the highest of any cutting tool material. The effect of temperature on the hardness of cutting tool materials is given in the fig. 5.01.

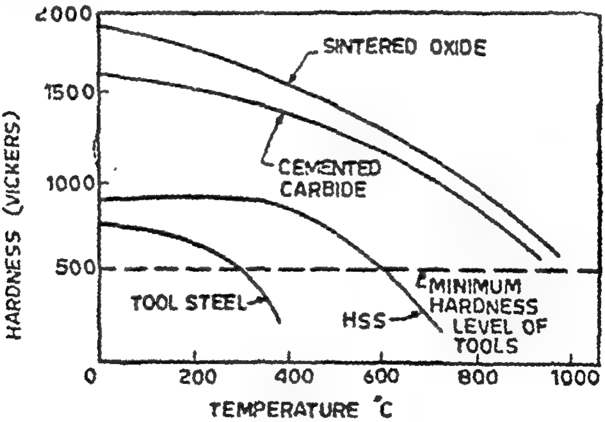


Fig. 5.01. Effect of temperature on the hardness of tool materials

2. *Abrasion Resistance* : Abrasion resistance is the ability to resist wear. Abrasion resistance not only depends on hardness but also on the extent of hard, undissolved carbides present. This

characteristic increases as the carbon and alloy contents increase. Steels high in carbon, chromium, tungsten, molybdenum and vanadium possess this characteristic. The abrasion characteristic in carbides is improved by adding a small percentage of tantalum.

3. *Toughness* : Toughness is the ability to resist shock or impact forces and also to resist a high unit pressure against the cutting edge. Punches and turning tools must have a high degree of toughness to resist breakage and chipping in service. Toughness of high speed steels is expressed in terms of "Izod impact test" whereas in the case of cemented carbides it is expressed by 'transverse rupture strength.'

4. *Thermal Conductivity and Specific Heat.* The combination of these two physical properties of a material is of prime importance for cutting tools. It is very much desired that tool materials should possess high thermal conductivity and specific heat so that the materials may conduct away the heat generated at the cutting edge.

5. *Coefficient of Friction* : The pair of work-tool material should possess low coefficient of friction. This would improve surface finish. reduce the heat due to friction at tool-chip interface and finally absorb less cutting energy.

6. *Machinability* : This is a property of the material which defines the ease with which a material would machine. The tool material should be comparatively easier to machine.

Other characteristics which apply to the tool-steels are :

(*a*) Resistance to deformation during the heat treatment of the tool steels. The shape and size of the tool must retain.

(*b*) Resistance to discarburisation when subjected to elevated temperature during cutting. Decarburisation causes soft spots on the tool surface which may get cracked due to quenching by the application of cutting fluid.

(*c*) Hardening temperature range may also govern the choice of tool steels. If high temperature furnaces are available high carbon, high-chromium or other high alloy types of

important characteristic *i.e.*, the ability to retain its cutting hardness at red heat temperatures upto 800°C.

Cast alloys of tool material grades usually have high transverse rupture strength, low coefficient of friction and execellent resistance to corrosion. Though the material is not as hard as HSS at room temperature but it retains its hardness and toughness at high temperatures. It readily absorbs shocks and impact. Resistance to abrasion and erosion are also noteworthy characteristics.

As a cutting tool it can be operated at speeds 50% to 100% faster than H.S.S because it retains its hardness beyond the point where H.S.S. 'burns up'. What is more, it will not loose its hardness after cooling from red heat.

Cast alloy is at its best when working at relatively high speeds with heavy loads that generate considerable heat. It bridges up the gap between the maximum speeds possible with high speed steels and minimum speeds practical with carbides. The material is preferred when formed tools are needed.

HSS	Cast Alloy	Carbide
15—30	30—60	60—300
Smpm	Smpm	Smpm

Cast alloy and steel have very nearly same coefficient of thermal expansion, as a result both the materials can be brazed and welded together with little danger of cracking during cooling.

A few typical compositions are

(*i*) 12-17% Tungsten, 30-35% Chromium, 45-55% Cobalt and 2% Carbon.

(*ii*) 17% Tungsten, 45% Cobalt, 33% Chromium and 3% Iron.

5.034. Cemented Carbides :

Cemented carbides are products of carbides of tungsten, titanium and tantalum with some percentage of cobalt. The product is obtained by a special technique known as '*Powder Mettallurgy.*'

The properties of Tungsten-Carbon alloys were firstly studied by a frenchman, Moisson in 1893. This alloy tungsten carbide contained 94% tungsten and 6% carbon. But the main credit for the development of this metal and its industrial applications was

with Germans. During World War I, Germans were trying hard to find a substitute for diamond in wire drawing industries. In this direction, research workers from Krupps and Osram joined hands and they developed a compact material which was relatively free from porosity and possessed hardness only to next diamond. They called it *Widia (Wid + Diamond = like a diamond)*. The research disclosed that if the fine tungsten carbide powder be mixed with a powder of lower melting point, pressed into suitably sized mould and heated to a temperature slightly above the melting point of the powder, tungsten carbide compact would result. This secret remained with Krupps upto 1926, when it was disclosed to other German industries. Since then, rapid strides have been made in Russia, Czechoslovakia, England, U.S.A and Japan. Recently, some successful attempts have also been made in the country towards the manufacture of carbides.

Properties of Tungsten Carbide :

(*i*) The material is abnormally hard and more brittle.

(*ii*) It can withstand a very high temperature of 1200°C and maintain its hardness.

(*iii*) It is very good in compression but fragile like a raw egg.

(*iv*) It provides higher tool life.

(*v*) It provides much better surface finish.

(*a*) Plain Tungsten Carbide Grade

This grade possesses only two constituents tungsten carbide and cobalt. The factors controlling the characteristics of this grade are the grain size of tungsten carbide particles and the cobalts percentage. The upper and lower limits for grain size are 8 micron and 1 micron respectively, whereas the maximum and minimum percentage of cobalt are 25% and 3% respectively. Its hardness decreases with increase in grain size and cobalt percentage. However, the toughness increases with grain size and cobalt percentage. It must be remembered that the most preferable composition is one which has lowest binder content and fine grain size for maximum tool life.

This variety or carbide is also known as single carbide.

(b) Steel Grade Tungsten Carbide

Straight tungsten carbide showed greater tendency to weld to steel during machining leading to 'Crater Wear'. In 1930, it was discovered that the addition of titanium carbide greatly reduced the susceptibility of sintered carbide materials to cratering. However, the addition of titanium does lower the strength of the finished product, therefore, high titanium grades are used for finish machining of steel and low titanium grades for roughing. A series of tests at General Electric Co. (USA) have been conducted and it has been established that 20% addition of volume of TiC reduced crater depth from 0.225 mm to 0.025 mm.

Tantalum carbide is sometimes added to plain tungsten carbide when the problem of crater and flank wear are encountered at the same time. Typical machining examples with such a grade are :

(i) Ferrous castings, where burnt-on sand is a problem
(ii) Heavy duty planing and milling operations etc.

The [illegible] of tantalum carbide is even less than tungsten carbide [illegible], it is very compact and offers good toughness properties. [illegible] material further possesses low coefficient of friction and [illegible] heat is generated at tool chip interface. Tantalum carbide can cut satisfactorily at lower speed of 30 M/min.

Applications :

(i) As cutting tool.
(ii) As die material.
(iii) As layer on corrosion resistant alloys.

Tungsten carbides that contain titanium carbide and tantalum carbides are also termed as *triple carbide*.

5 : 35. Ceramic Tool Materials

The following cutting tool materials are known as [illegible] :

1. Aluminium Oxide.
2. Silicon Carbide.
3. Boron Carbide.
4. Titanium Carbide.
5. [illegible]

It appears that the name 'ceramic' has been derived from the fact that these materials are made by sintering the elements at extremely high temperature approaching to that of pottery-ceramic.

Amongst all the above tool materials the best machining results have been obtained with sintered alumina. A well known variety contains 99% Al_2O_3 and the remaining 1% is shared by Cr_2O_3, MgO and NiO.

Characteristics of Ceramic Tool Material :—

1. Poor thermal conductivity and refractoriness due to which the cutting edge remains unaffected even when the chip is red hot. This property allows higher cutting speeds to be used than are possible with carbides.
2. Being an oxide, it is stable in air upto its melting point of 1800°*c*.
3. Its corrosion resistance to the strongest acids and chemical is outstanding.
4. It is non-magnetic and non-conducting to electricity.
5. It has a high compressive strength (30,004—35,000 kg/cm²).
6. It possesses relatively superior hardness values both at low and high temperatures.
7. The material can not be wetted by molten metal, therefore, the problem of built-up-edge is never encountered.

Advantages claimed with Ceramic Tools :—

1. Higher Cutting Speeds : The materials can be machined at fantastic speeds. Cutting speeds upto 800 m/min have been successfully attained wtth ceramics. The most practical range is 200—600 m/min. Higher speeds save machining times and reduces machining costs by producing more components per hour.
2. Longer tool life : The rate of tool wear is verylow

even while machining cast iron, stainless steel and high strength alloys.

3. Reduced Built-up-Edge : The work material can not weld and form BUE.

4. Superior surface finish : Surface finish upto 20 micro-inches on harder steels and 30 micro-inches on cast-iron can be easily obtained. This eliminates further finishing operations in certain cases.

5. Coolant is not needed : If at all any coolant is recommended then it is for keeping the work distortion to minimum.

6. Lower coefficient of friction : The coefficient of friction between the chips and tool face is low due to which lesser heat is generated in machining. Most of the heat goes with chips.

7. Greater machining flexibility : Only one type of ceramic tool can successfully machine a wide range of metals at various speeds ranging from 200 mpm to 800 mpm. The tool can safely be used on interupted cuts.

is very difficult to stop the spindle at high speeds therefore, the machine should have a variable speed drive.

It is again another credit to Germans who introduced this material to industries for the first time in 1930 at Siemens & Halske A.G. At present Russia and U.S.A. are the other countries who have adopted ceramics in the industries to a very large extent.

5.036 Diamond

The diamond is a noble material which is so costly that its applications to the metal machining will not prove economical unless and until the special circumstances warrant for it. It is widely used only for truing the grinding wheels and to some extent for fine finishing of the metals. In metal machining small diamond bits are used for precision jobs such as finishing operations on bearings, hard rubber, celluloid and hard steels. Use of large diamond bits for deeper cuts will be uneconomical and hence the material is used in a very small grit size, which shall only suit finishing operations with shallow depth of cuts at higher cutting speeds.

Diamond is extremely hard material and show large resistance to abrasion. Due to high compressive, bending strengths and modulus of elasticity its deformation in process is least. It possesses high heat conductivity and melting point. It offers highest tool life (50 to 100 times more than cemented carbide tools) and mirror like finish by direct turning. The handling of tool should be very careful for protecting it from any damage.

Experiments have shown that the machine tools using diamond tools should be free from vibrations and capable of running at higher speeds. If handled carefully, the diamond gives the tool-life as high as four times the tool life of carbide tools.

Applications : Diamond tools have been successfully used in the production of rocket motors, electronic component made of ceramics, pressings of berryllium etc. New machining processes are also in development in which diamond abrasive belts having diamond electrostatically deposited are used for machining television screens.

4.04. CHIP BREAKER

Continuous chips are produced while machining ductile materials such as steel and aluminium. The disposal of such long ribbon like chips has never been a problem while machining with high speed steel but the introduction of carbide and ceramic tools has increased the machining speed and chip production to 3—5 times to that of H.S.S. tools. At such a high speed of machining the chips leave the cutting edge at a very high velocity which are dangerous to the operator as the chips are hot and sharp. This has led to the development of a device known as chip breaker. The device is located near the cutting edge where it obstructs the flow of the chips and makes them to curl immediately. The curled chips break either because of the tight curling or due to their striking on the face or shank of the cutting tools.

Reasons for using the chip breaker

1. The chips are dangerous to the operators since they are hot and their edges are sharp and serrated.

2. Long spiral chips are difficult to dispose and occupy more space.

3. Hot and sharp edged chips may damage the instruments and machine painting.

4. The chips interfere with the flow of coolant and thus use of coolant becomes less effective.

5. The emerging chips also spoil the newly generated surface.

Disadvantages of a chip breaker

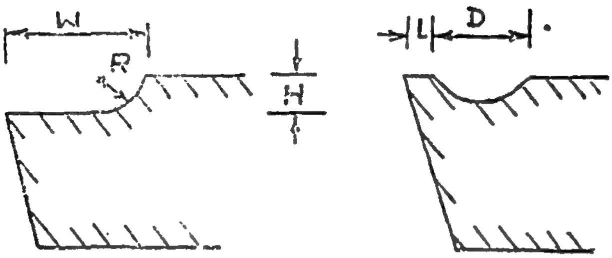
1. It increases the cost of the cutting tool.

2. The cutting forces increase.

3. The power consumption increases and the increase has been seen as high as 2[illegible]

Types of chip breakers :

- Chip Breakers
  - Ground-in Type
    - Step Type
    - Groove Type
  - Clamp-ed Type



(*a*) Ground-in Step Type (*b*) Ground-in Groove Type

Fig 5.02 Ground-in type of chip breakers.

Basically, there are two types of chip breakers. The ground-in type is produced at the cutting edge by making a short-step or groove by grinding. In the the case of step type chip breaker the step deflects back the chip into the workpiece or the side of the tool where it breaks. The approximate dimensions for depth and radius are around 0.5 mm. The width increases with depth of cut and feed the variation is 1 mm to 5 mm. In the second type of

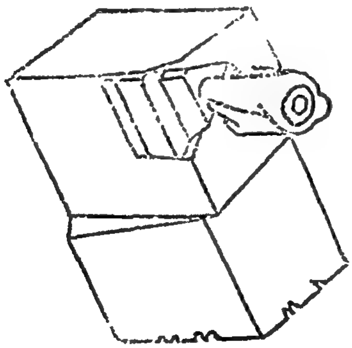


Fig 5.03 Clamp on Type of Chip Breaker

chip breaker the groove is essentially meant for curling the chips and not for breaking them. The dimensions of land, and groove are fuuction of the feed *e.g.* land varies from 1 to 1.5 time's feed

and the groove varies from 3 to 4 times the feed. The depth is normally 0.1 mm. With the development of inserted carbide tool it is now possible to provide the grooves on the inserts during manufacturing process by pressing techniques.

The clamp-on chip breakers (fig. 5.03) are usually adjustable type of breakers. If the ground-in type breakers are economical then clamp-on type are simple and versatile. Initial cost may be very high but cost per component certainly comes out much smaller. Due to the provision for adjustment it can be effectively used over larger cutting ranges and materials.

QUIZ

1. State the factors responsible for the development of newer tool materials.
2. Define the terms ; Red Hardness, Abrasion Resistance and Toughness as applied to cutting tool materials.
3. Why high carbon steel can not be totally eliminated from the family of cutting tool materials ?
4. Discuss the role of tungsten. chromium and vanadium in high speed steel.
5. What is Tantung ? Mention a few characteristics and applications of Tantung.
6. Differentiate between plain tungsten carbide and triple tungsten carbide.
7. Write down a brief note on machining with carbides & oxides.
8. What materials are included under ceramics ?
9. Enumerate some precautions while working with diamond.
10. What part the chip breakers play during machining of the metals ?
11. Why chip breakers must be used with carbide and oxide tools ?

CHAPTER 6

CUTTING FLUIDS

Before the discovery of high speed steel, the selection of a cutting fluid was not a problem with the machinists. The machining was done at much lower speeds and water served to them as a useful coolant. With the development of newer tool materials and use of higher cutting speeds during machining, the part played by a cutting fluid was studied to very great depth both by the manufacturers of the oils and the metal machining engineers. As a result, it has been established that the use of a right type of cutting fluid during machining positively improves the machining operations. The improvement is brought about through a complex cooling and lubricating mechanism which affects the tool life and work-finish.

5.01. FUNCTIONS OF THE CUTTING FLUID

The first and foremost function of a cutting fluid is to cool the tool and the workpiece. The stream of coolant falling on the backside of the chip carries away most of the heat and lowers the shear zone temperature. To provide lubrication and to wash away the chips may be treated as its secondary function. With these three as main functions of the cutting fluid, it is possible to say that a cutting fluid—

1. Improves the tool life.

2. Permits the use of higher cutting speeds for larger metal removal rates.

3. Lubricates the chip-tool interface ; thus, reduces the kinetic coefficient of friction and keeps down the cutting forces.
4. Improves the surface finish by protecting the newly generated surface from oxidation and corrosion.
5. Reduces the formation of built-up edge.

5.01. ACTION OF CUTTING FLUID :

As has been listed down above, the main functions of the cutting fluid are cooling, lubricating and flushing away the chips. The work carried out by Merchant throws some light on the action of cutting fluid but his theory does not stand as perfect because of high speeds used during machining. Most of the work done by Merchant was at low speeds.

Merchant developed an imaginary picture of cross-section of a portion of the chip-tool interface (fig. 6·01) based on photo micrographic evidences. He assumed that due to uneven surfaces of the tool face and the chip there existed minute voids (1 & 2) at the chip-tool interface. The cutting fluid penetrates into the voids

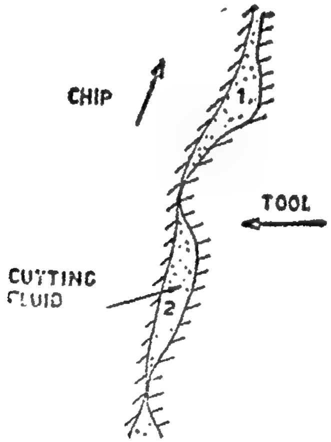


Fig. 6·01 Imaginary and Magnified Picture of Chip-Tool Interface

due to vacuum in the voids. The fluid would react chemically with the clean surface of the chip under high pressure and temperature and thus, producing a soft film of a chemical compound between chip and the tool. This should prevent the metal to metal

contact and reduce the friction and the formation of built-up edge.

The explanation due to Merchant shows the way in which the cutting fluid acts as a lubricant besides a coolant. However, the validity of the explanation is doubtful because the cutting fluid will never get an opportunity to enter into voids due to high relative velocity of the chip over the tool-face. Even if a little of it has entered in the voids, it is never possible to avoid the metal to metal contact as the extremely high pressure 5,000 kg/mm^2 at the cutting edge is sufficient to rupture the film of the cutting fluid in between the chip and the tool face. Therefore, the Merchant's theory of cutting fluid may be treated valid at low speeds of machining and never at higher speeds of machining. At higher speeds, the cutting fluid acts only as a coolant and reduces the tendency of chip welding to the tool-face. In this way, it may improve the tool life and the surface finish of the work.

5.03 REQUIREMENTS OF A GOOD CUTTING FLUID

1. Should have good wetting characteristics for the materials being machined.
2. Should not gum the moving parts of the machine tools.
3. Should not foam easily.
4. Should not deteriorate in storage.
5. Should possess high specific heat and heat conductivity : so that it removes the heat rapidly.
6. Should possess excellent rancidity control capacity.
7. Should be odourless and transparent.
8. Should prevent the electrochemical process of rusting.
9. Should cost low.
10. Should possess high flash point.

5.04 TYPES OF CUTTING FLUIDS

5.041 Gaseous Type :

Air (still or compressed), carbon di-oxide, Argon and oil-mist are some notable examples of the cutting fluids included in this category. Such types of fluids are always applied through a

nozzle under pressure. Ordinary air is never preferred because of its poor cooling, lubricating and anti-siezure properties. Air is only preferred as a coolant when the cutting conditions do not permit the use of and other cutting fluid. Surface grinding and metal cutting with a hand saw are illustrative examples where air acts primarily as coolant besides removing the chips from the cutting zone. In some limited cases sub-zero cooled air is also being used. The other type of widely used gaseous type cutting fluid is liquid CO_2. It possesses excellent property of extracting the heat from a body due to sublimation of CO_2. However, its use is very limited because of its higher cost which can only be substantiated by maching at higher cutting speeds.

5.042 Liquid type :

(*a*) **Water :** Plain water and soda-water are the earliest known cutting fluids. Even today, water containing alkali or antiseptics (tri-sodium, phosphate and chlorine) is used freely where cooling and washing away the chips are needed during machining. Water is the most freely available, cheapest and almost best cutting fluid from the point of view of high heat conductivity and specific heat. Extra care has to be maintained while using water, otherwise it may develop rust on the machine tool elements. The other drawback with water is that it possesses high surface tension due to which it balls up on the surface and does not spread over the surface.

(*b*) **Oil base cutting fluids :** These fluids are also known as straight oils. They may be mineral oils of any viscosity or fatty oils.

(*i*) *Straight Mineral Oils* :

Such oils possess lower viscosity and have faster wetting and penetrating action. They have been found most suitable for light duty operations on non-ferrous metals like aluminium, brass and magnesium. Besides, these types of fluids are largely recommended for machining on automatics, where cooling and lubricating requirements are not very severe. The use of an emulsion on such machine might cause trouble on the machine tool by mixing with its

lubricant. This would certainly require the replacement of the lubricant and hence, stopping the automat. The greatest use for a straight mineral oil in metal machining today is as a blending medium ; to be mixed with a base cutting oils havihg high lubricating value to meet operating conditions.

(*ii*) *Fatty Oils* :

Sometimes back, the fatty oils were very common for heavy duty machining work. However, their use is now very limited due to higher cost. The other reason for their limited usage is the tendency of oils to become rancid due to which they start giving bad smell. The oils also breed bacteria and develop skin trouble to the operator. They tend to glaze the work specially, when used in connection with machining tough alloys.

The most popular fatty oils are *lard oil* and *sperm oil* which are only used on tough non-ferrous alloys.

(*ii*) *Blended Fatty Mineral Oils* :

The product of fatty and mineral oils is obtained by mixing 10% to 30% of fatty oil with mineral oils of different viscosities. Several advantages are derived by the blending of the oils.

1. The cost of fatty oil is reduced.
2. Improved surface finish is obtained on nonferrous alloys and steels.
3. Penetrating and wetting characteristics are also improved.
4. The blended oils do not have any undesirabie effects.
5. The little amount of fat is sufficient to act as lubricant by forming metal soaps at chip-tool interface.

Extensively used in automatic screw machines where a better surface finish is required than could be obtined by using straight mineral oils ; because of their non-corrosive nature, the oil can also be used on copper and its alloys.

(*iv*) *Sulphurised Blend of Fatty Mineral Oils* :

Sulphur can very well combine with fatty oils. Sulphur increases cooling and lubricating characteristics. These days

sulphurised oils are being widely used as alround cutting fluids particularly. where steels and non-ferrous metals are worked on the same machine, and on multi-spindle automats. On the automats, this type of blended oil serves triple functions *i.e.* coolant, lubricant and hydraulic fluid.

The blended oil is also treated with chlorine and the name accorded to such a fiuid is sulphurised chlorinated fatty-mineral oil blend. The performance of sulphurised oil is superior to that of soluble oil at normal temperature.

(*c*) **Water Miscible Cutting Fluids**

(i) *Emulsions of Soluble Oils :*

A soluble oil is a mineral oil or fatty oil which contains an emulsifier, such as soap. An emulsion is a product which, when mixed with water, forms milky dispersions wherein very fine oil droplets are in physical suspension in the water. All emulsions exhibit very good cooling characteristics due to higher percentage of water in them Therefore, for higher metal removal rates an emulsion of soluble oil is always preferred over straight oils. A few notable examples of machining operations, where such a fiuild is extensively used, are turning, drilling, centre-less grinding and milling. In all these operations rate of metal removal is quite high and cooling is the prime requirement. When circumstances warrant for better lubricating property in an emulsion, then *extreme pressure additives* like chlorine, sulphur and phosphorus are added. Such emulsions are benefically being used on many operations such as broaching, tapping threading and hobbing.

Despite of large many advantageous features in it, the soluble oil is always associated with some limiting factors. It has a tendency to rust or corrode the parts of the machine tool or mix with the oil meant for lubricating machine bearings.

6.05 CHEMICAL COOLANTS

Chemical coolants are blends of a number of chemical components dissolved in water. All of them are used as coolants bnt some of them very well exhibit lubricating properties also. The flow of coolant also helps the chips to break by reducing its

ductility through partial cooling. Such chemical coolants may be elassified into three groups :—

(*i*) Pure Coolants—These contain no lubricants and are made up mostly of water softners and rust inhibitors.

(*ii*) Coolants with mild lubricity—Such fluids contain water softners, rust inhibitors and wetting agents

(*iii*) Lubricating Coolants—The coolants contain water softners, rust inhibitors, wetting agents and chemical lubricants ; Chlorine, Sulphur or Phosphorus additives are present either alone or in combination.

Since chemical coolants are basically water modifiers, they are particularly, recommended for those machining operations in which the main function of the cutting fluid is to act as a coolant.

(*a*) Amines and Nitrites—for rust prevention.

(*b*) Phosphates and Borates—for water softening.

(*c*) Soap and Wetting Agents—for lubrication and reduced surface tension.

(*d*) Glycols—As blending agent.

(*e*) Germicides— for controlling bacterial growth.

Reasons for Using Chemical Coolants :

There are three reasons for using a chemical coolant during machining :

1. They give high metal removal rates.
2. Chemical coolants last longer than other machining fluids.
3. Chemical coolants do not clog the pipe. They also help in setting and recovery of chips.

6.06 SOLID LUBRICANTS

Usually there are two types of additives. One type of the additives is only active upto a temperature of 200°C. Such additives are fats, fatty acids, alcohols and esters. These additives are also known as *lubricity additives*. The second type of the additives is effective after 250° C and remain so upto a

removal rates require an ample supply of cutting fluid at moderate velocity and without interruption. There are two most effective ways of applying cutting fluids (fig 6.03).

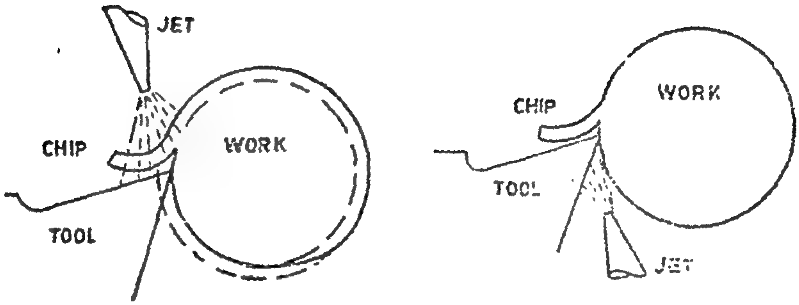


Fig. 6.03 Two methods of using cutting fluids while turning

The first one is the conventional method while the othor one has proved very useful in the turning operations. Considerable improvements in the tool life and surface finish have been obtained with the second method while turning.

The cutting fluids may also be applied in the form of mist. Mist is obtained by passing compressed air and cutting fluid through a nozzle. The fluid thus, gets atomised. Mist cooling has not been found very advantageous in the case of heavy duty machining but very effective in high speed machining jobs. The heat dessipation is due to expansion of air and evaporation of cutting fluid. Further, the mist may also reach tool-chip interface and act as lubricant. It has ons serious drawback that cutting fluid cannot be recovered.

TABLE V

Suggested Cutting Fluids for Turning & Milling.

Materials	*Turning*	*Milling*
Aluminium & its alloys	Kerosene	Kerosene
Alloy steels	Sulphurised Mineral Oil	Sulphurised Mineral Oil
Low Carbon Steel	Soluble Oil	Soluble Oil
Copper	Sulpho-Chlorinated Oil	Sulpho-Chlorinated Oil
Malleable C.I.	Dry or soluble oil	Dry or sol. oil
Brass & Bronze	Dry or paraffin oil	Dry or paraffin oil
Monel Metal	Sulpho-chlorinated oil	Sulpho-chlorinated oil
Magnesium	Dry or Mineral Oil	Dry or Mineral Oil
Grey C.I.	Dry or soluble or oil	Dry or soluble oil

Note :—Use coolants in large quantities or none at all. Intermittent or insufficient quantity of coolant may result in cracked cutting tool surface.

QUIZ

1. What is a cutting fluid ?
2. State some of the functions of cutting fluid.
3. Mention any four important requirements of the cutting fluid.
4. How does the cutting fluid reach the tool-chip interface ?
5. Why the cutting fluid act only as a coolant at higher cutting speeds ?
6. What are the main groups of the cutting fluids ?

7. Under what circumstances would you recommend the use of—

(i) Extreme pressure emulsion.
(ii) Chemical coolant.
(iii) Liquid Carbon di-oxide.
(iv) Compressed air.
(v) Straight mineral oil.
(vi) Sulphurisee fatty-mineral oil blend.

8. Write a brief note on the suitablity of water as a cutting fluid.
9. What are the different ways of applying cutting fluids ?
10. How does cutting fluid improve the tool life ?

CHAPTER 7

FUNDAMENTALS OF MACHINE TOOLS

Machine tools are essentially metal cutting machines. They are employed for shaping the metals by machining out the surplus material from the stock. The surplus material comes out in the form of chips. This family of machines possesses a very novel feature which distinguishes it from the other groups of machines. "Machine tools are capable of producing themselves." Therefore, the machine tools, are quite often referred as 'mother machines'. To justify this novel feature, all the machine tools are expected to perform within a high degree of accuracy consistently over a long period. Further, to meet out this requirement, the machine tools must possess good rigidity both. static as well as dynamic and some flexibility to accomodate the changes in the operational conditions. The term 'rigidity' means the capacity of machine tool structure to resist the deformation which may be introduced due to the cutting forces generated while machining. A machine tool structure experiencing larger deformation is poor in rigidity and any component made on it will be out of dimension. It will also have poor surface finish. If the rigidity of the machine tool structure is tested by dead load when the machine is not running, it is termed a- static rigidity test on machine tool. If W is load applid and δ is the deflection caused in the machine tool structure, then

$$\text{Static rigidity} = W/\delta \qquad \text{kg/mm}$$

Elements of a Machine Tool :

Every machine tool is basically composed of four elements :

7.01. Structure formed by bed, column or frame

7.02. Slides and slideways

7.03. Spindle and

7.04. Drive Regulators

7.01. STRUCTURE (Bed, Column or Frame) :

The structure of machine tool is formed by bed, column or frame and it comprises as a rule, a considerable part of the total weight (approximately 70%) of the machine. The structure provides stability to the machine tool, supports the members and maintains alignment among the moving members. During machining, the structure is subjected to bending and twisting moments and if the structure does not possess sufficiently high rigidity, it would undergo appreciable deformation. Therefore the bed, column and frame must possess proper rigidity. This is assured in a machine tool either by selecting a right type of material or a suitable section of the structure. The strength of hollow machine frames is increased by ribs and partitions which are specially necessary when the operating conditions of the component do not allow it to be completely closed so that it remains open on one or two sides. This is the case in the lathe beds, so that chips can fall through the bed and be easily removed. The beds in many lathes consist of two walls connected by a system of ribs and partitions. A typical section of lathe bed is shown as fig. (7·01).

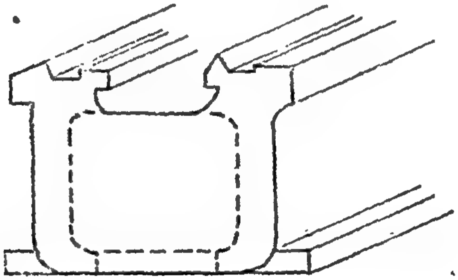
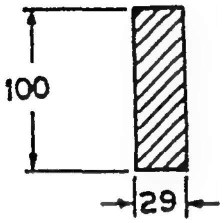
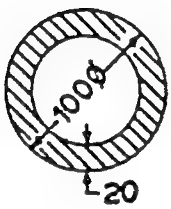
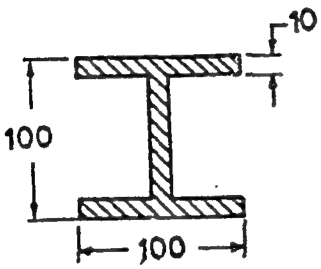
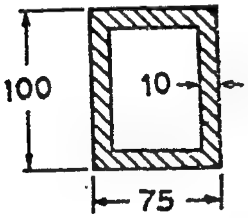
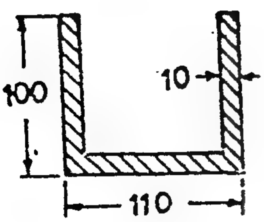


Fig. 7.01. A Typical Section of Lathe Bed

For right type of section to be used for bed, column and frame, several kinds of sections having approximately same cross sectional area and other parameters have been compared on the basis of bending and twisting stiffnesses. The values as tabulated in Table VI show that box type section is most suitable. It offers maximum resistance in twisting and in the bending the resistance is next to I-section. In practice box section is used after certain modifications.

TABLE VI

Section	Area Cm^2	Weight	Bending moment	Twisting moment
	29	22	$48.3\times\sigma_b$ (1)	$2.7\times\tau_t$ (1)
	28.3	22	$58.2\times\sigma_b$ (1.2)	$116\times\tau_t$ (43)
	29.5	22	$90\times\sigma_b$ (1.8)	$12\times\tau_t$ (4.5)
	29.5	22	$66.3\times\sigma_b$ (1.4)	$104\times\tau_t$ (38.5)
	29	22		

Usually, the bed of machine tools is made of cast iron. The reasons for adhering to cast iron are :

(i) Cast iron possesses better shock absorption capacity.

(ii) Cast iron possesses better lubricating property due to free graphite in it.

(iii) Cast iron shows higher compressive strength.

(iv) Cast iron can be alloyed with nickel, chromium and molybdenum, which are added for increasing hardness and reducing the effect of residual stresses.

Some attempts have also been made to use wear resistant beds by mounting heat treated slides on the top of the bed but such beds are not very popular.

The only drawback with cast iron beds is the great difficulty encountered in preparing intricate castings. Structures with intricate details are now prepared by fabrication. In recent years welded frames for uprights, base plates and saddles have been increasingly used instead of cast iron and all-cast steel frames. But it is yet to be seen if welded structures will replace cast structures. By comparing the advantages and disadvantages of both the types, we can suggest the fields where they will be most effective. The welded frames have proved very suitable for heavily loadedframes.

7.02 SLIDEWAYS & GUIDES

Slideways are provided on the machine tool structures for guiding the movements of the slides, and carrying either the work or the tool. They are also responsible for maintaining the alignment of the guided parts at all respective positions.

The slideway may be integral part of the structure or added separately to the structure at its top face. These ways are provided in vertical or inclined plane so that the falling chips do not rest over the slideways. Other considerations for designing suitable slideways are given below :

1. Minimum wear and provision for the compensation of any wear developed after its use over sometime.

2. Provision for effective lubrication.

3. Deformation due to cutting forces should be least.
4. Possibility of chips getting entrapped should be minimum.

The above listed considerations depend to a large extent on the type of materials selected for slideways and guides therefore very much importance is given to the right selection of the material.

Grey cast iron is a very common material when slideways are finished on the structure itself. The hardness of the ways can be increased by flame hardening to improve wear resistance characteristics. When the slideways are added separately on the structure, then steel strips duly hardened by carburisation are preferred. These strips are either welded or screwed on the structure. Recently, there has been found a to trend use plastic strips. Since plastic possesses antiscoring and anticorrosive properties. Usually these types of slideways are preferred on such machine tools where rigidity is not the main consideration. Zinc alloys and bronze have also been used in special circumstances.

Machine tool slideways may be classified into four distinct classes as indicated in fig. 7·02 All the four types have distinct

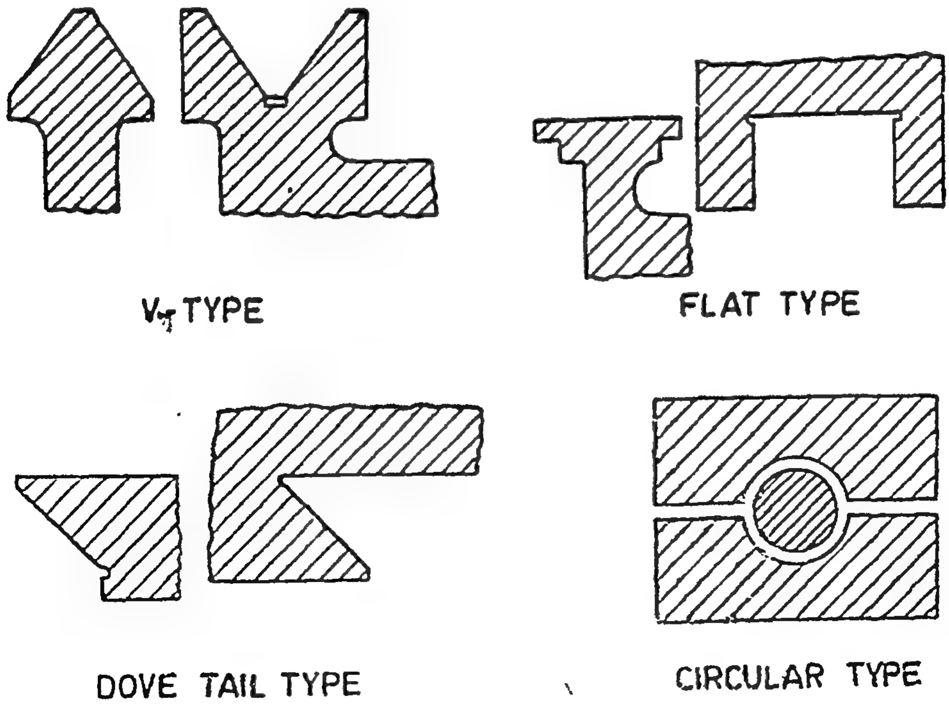
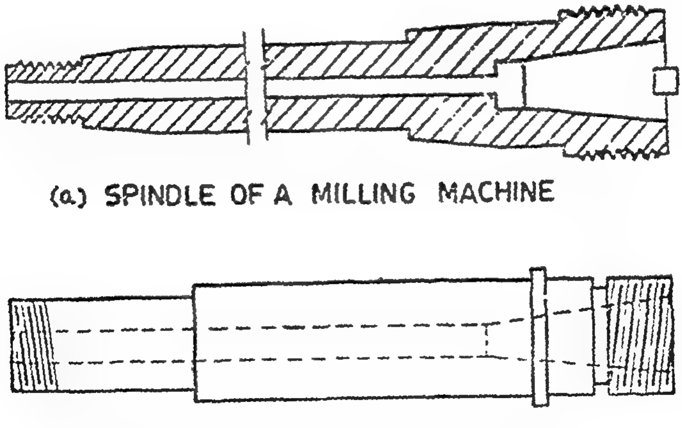


Fig. 7.02. Basic Types of Slideways

merits and demerits over each other. Therefore, a combination of these slideways are preferred on the machine tools. The V-type slideways are advantageous as they are of self-adjusting type. Under the weight of moving parts and the cutting forces the mating surfaces remain in contact with each other and the possibility of any play is eliminated. On the other hand, flat type slideways are simpler in construction and offer quite a large bearing area to the moving parts. Dove-tail type slideways are preferred when the location of the moving parts is considered essential. Cylindrical slideways are commonly seen with the radial drill and milling machines.

7·03 SPINDLE UNIT

Machine tools like lathe, drilling machine, milling machine and grinding machine etc. are equipped with spindles for either locating, holding or driving the tool or the work. As such spindles are required to possess high degree of rigidity, rotational accuracy and wear resistance characteristics. The spindles of general purpose machine tools are normally subjected to heavier loading than the spindles of precision machine tools. Therefore, the major requirement in the former class of spindles is the rigidity while for the later class the prime consideration is the material accuracy.



(a) SPINDLE OF A MILLING MACHINE

(b) SPINDLE OF A LATHE MACHINE

Fig. 7·04 Types of Spindles

The spindles are normally made hollow and provided with internal taper at the nose end to receive the centre or shank of the cutting tool. In case of the spindles the external screw threads are

cut at the nose end to receive the chuck or face plate on it (Fig. 7·03). Medium carbon steel containing 0·50% Carbon is employed for making the spindles which is then heat-treated by quenching and tempering to achieve a surface hardness of 22—38 R_c. Low carbon steel containing 0·2%C can also be used, it has to be case carburised, quenched and tempered to attain a surface hardness of 50—60 R_c. Spindles for high precision M/c tools are hardened by nitriding as it provides sufficient hardness with least deformation Manganese steel is used for spindles of heavy duty machine tools.

The spindles are supported inside the housing by means of one or more than one pair of bearings which may be ball and roller bearings or antifriction bearing. The chief purpose of the bearings is to maintain high accuracy of performance of the spindle. However, it improves the rigidity of the unit to a great extent. Preloaded bearings and bearings with an increased number of balls or rollers are usually used to reduce the detrimental effect of clearance and to increase the rigidity of the supports. Antifriction bearing material is choosen on the basis of performance requirement of the machine tools taking into consideration wear resistance, cutting forces heat conductivity, coefficient of friction etc. Some of the materials in order of their performance characteristics could be listed as cast iron, bronze, and babbit metals. Castiron is only suitable when the revolutions are very low. Recently the use of externally pressurised (hydrostatic) bearings has also been successfully made in machine tool's spindles

7·04 DRIVES IN MACHINE TOOLS

Machine tool drives can be broadly classified into two classes-stepped drives and sub-classified into four classess, viz mechanical electrical hydraulic and pneumatic types. Many of the modern machines have combined drives such as electromechanical, hydroelectrical etc. Amongst these the most widely preferred is the stepped mechanical type drives in the machine tools for one simple reason that they are easier to design and rigid in construction.

7·041 Principle of Stepped Regulation

Machining of metals should be done at right cutting speeds. In

the case of cylindrical work pieces the cutting speed (V_c) is related to the diameter of the work and the spindle speed (N) by the relation

$V_c = \frac{\pi D N}{1000}$. Since the cutting speed is taken constant for a particular work-tool pair, the spindle speed must vary as the work diameter changes. Graphically, the relation between V_c, D and N can be represented in the manner shown in the fig. 7·04. Such a diagram is called '*ray diagram*'. In the case of turning as the machining proceeds, the work diameter is reduced. For economic reasons it is essential that the spindle speed must increase with the decrease in the diameter. To meet this requirement, a regulatory device is always incorporated in between the motor and the spindle which may provide a stepped or stepless regulation for a spindle speed. For designing a stepped regulator, it is very necessary to establish a law that would govern the range of speeds at the spindle.

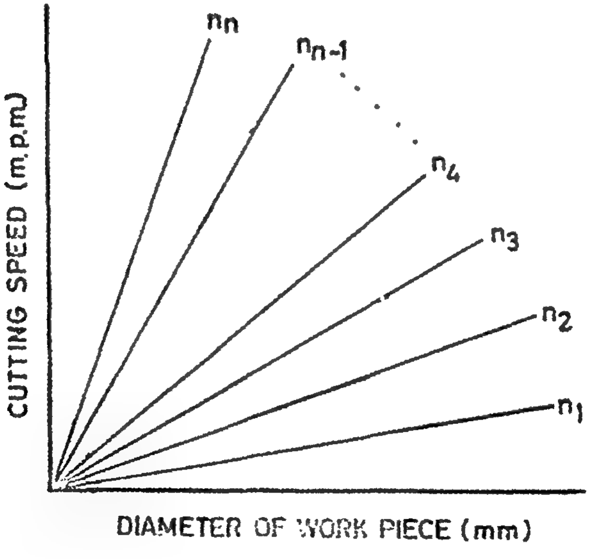


Fig. 7·04 Ray Diagram

Let us consider a ray diagram (Fig. 7·05) where the cutting speed V_A for a work diameter D_A is not available and the nearest available spindle speeds are n_p and n_{p-1}. The work can now be

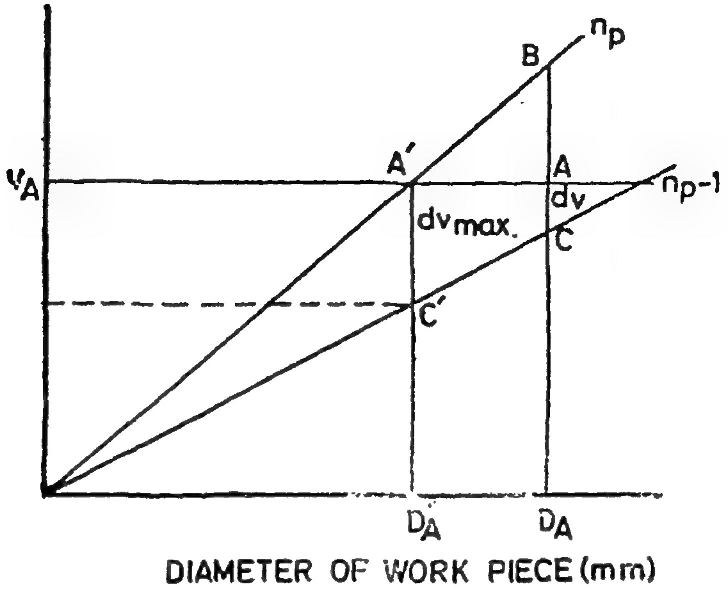


Fig. 7.05

turned either at a higher value or lower value of the cutting speed *i.e.* V_B or V_C respectively. From the consideration of tool life the lower speed V_C is preferable. But this choice brings in a relative loss (d_v) the cutting speed which amounts to $\frac{V_A - V_C}{V_A}$. This loss in speed goes on increasing as the turning continues and the work diameter reduces. The loss attains the maximum value when the work diameter reduces to D_A^1. Therefore, it is always advisable to choose spindle speeds in such a manner so that the maximum relative loss (dv_{max}) remains constant in going from one speed to the next. That is

$$dv_{max} = \frac{V_A^1 - V_C^1}{V_A^1}$$

$$= 1 - \frac{V_C^1}{V_A^1}$$

$$= 1 - \frac{D_A^1\, n_{p-1}}{1000} \cdot \frac{1000}{D_A^1\, n_p}$$

$$= 1 - \frac{n_{p-1}}{n_p}$$

For dv_{max} the ratio $\frac{n_{p-1}}{n_p}$ must be constant and $n_p = \phi n_{p-1}$

Where ϕ is a constant.

The speed range works out to be n_1

$$n_2=\phi n_1$$
$$n_3=\phi\, n_2=\phi^2\, n_1$$
$$n_4=\phi\, n_2=\phi^3\, n_1$$
$$n_n=\phi^{n-1} n_1$$

This reveals that the speeds must form geometric progression with the a common ratio ϕ There :

$$\phi=\sqrt[n-1]{\frac{n^n}{n_1}}$$

Usually, the value of ϕ is 1.06, 1.12, 1.26, 1.41, 1,58, 1.778 or 2.0. These numbers belong to *Renard Series* and are known as '*preferred numbers*'. The complete 'ray diagram' is given in fig 7·06.

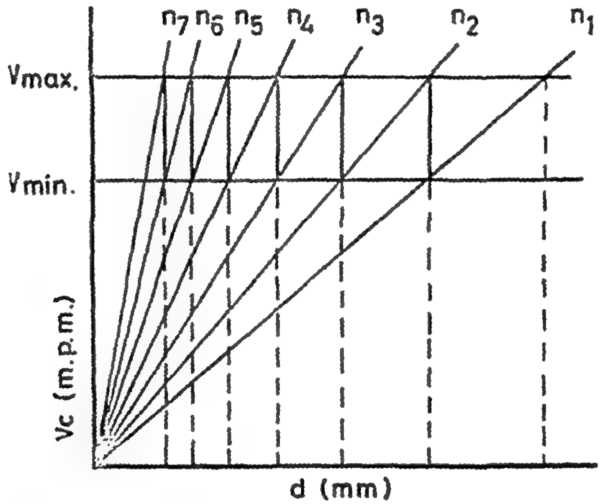


Fig. 7·06

Layout of a Gear Box :

In the most simple case the gear box of a machine tool possesses two shafts viz. a driver and a driven. But such a simple gear box is difficult to locate on a machine tool. Practically, all the machine tools have more than two shafts. The shafts in between the driver and driven may be called intermediate shafts. The speeds on the intermediate shafts may be quickly obtained by a graphical solution. The speeds are plotted vertically on a logarithmic scale with log ϕ as an unit. The shafts are shown by vertical equidistant and

parallel lines. The possible graphical solutions for six spindle speeds have been shown in the fig. 7.07 for a three-shaft gear box. Such diagrams are known as *speed diagrams.* In the above figures, the diagrams at (*a*) and (*c*) are known as '*narrow ray diagrams*' and those at (*b*) and (*d*) are known as '*wide ray diagrams*'. The narrow ray diagrams give compact gear boxes for the machine tools. However, in practice it is very difficult to obtain such diagrams because of several difficulties. The following two points should always be kept in mind while developing a layout of a gear box.

(*i*) the transmission ratio between a pair of gear should be less than 2 : 1 and higher than 1 : 4.

(*ii*) The maximnm possible speed range ratio should be 8.

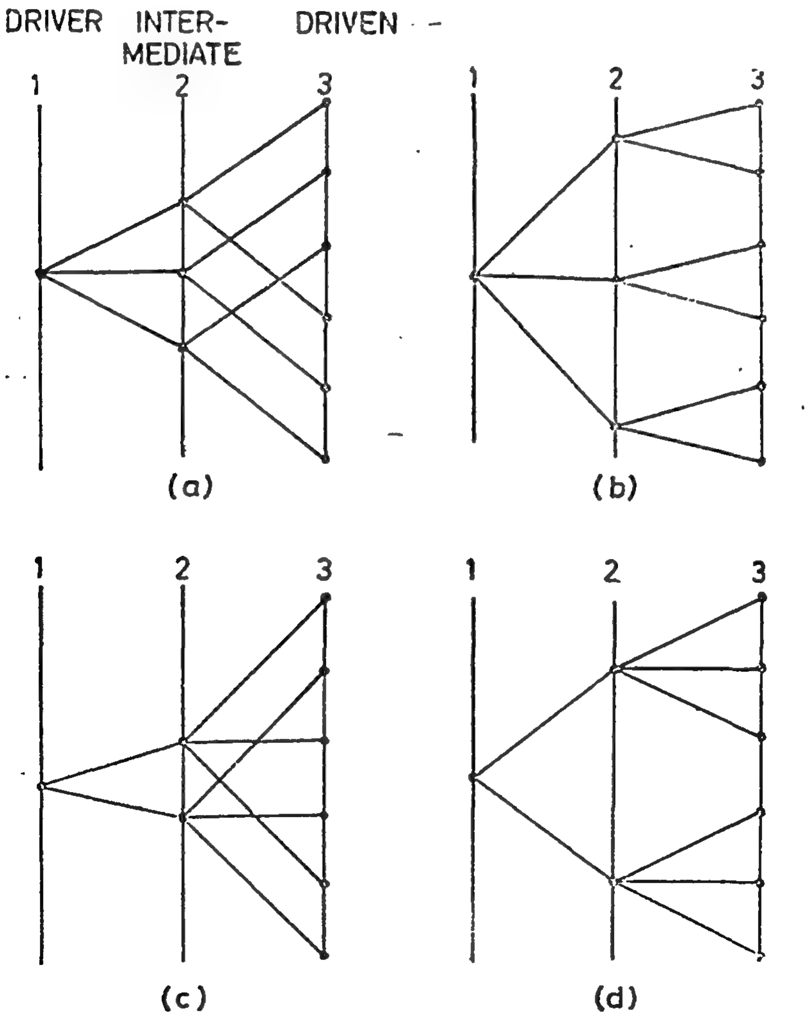


Fig. 7·07 Speed Diagrams

Example 1

Obtain the six spindle speeds of turret lathe if the maximum and minimum speeds are 960 rpm. and 30 rpm. respectively.

Solution :

$$\sqrt[6-1]{\frac{960}{30}}=2$$

$\therefore$ Speeds are — 30, 60, 120, 240, 480, 960

Example : *Design a gear box for a drilling machine to give speed variation between 100–250 rpm in 9 steps. The input shaft runs at a constant speed of 300 rpm and the out-put speeds are to be in geometric progression.*

$$\text{Speed range ratio} = \frac{250}{100} = 2{\cdot}5$$

$$\text{Step ratio } (\phi) = \sqrt[9-1]{2{\cdot}5}$$

$$= 1{\cdot}12$$

Hence the output speeds are

100. 112. 125, 140, 160, 180, 200, 224 and 250

The arrangement of gears in the gear box is shown in fig. 7·08 (*a*)

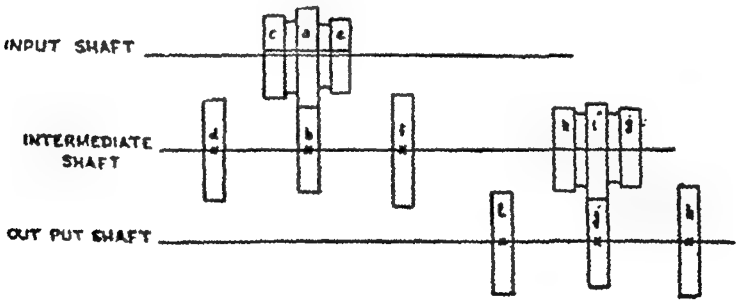


Fig. 7·08 (*a*)

The speed diagram corresponding to the gear box is shown in fig. 7·08 (*b*). The figure also shows the combinations of various gears to give the desired speeds.

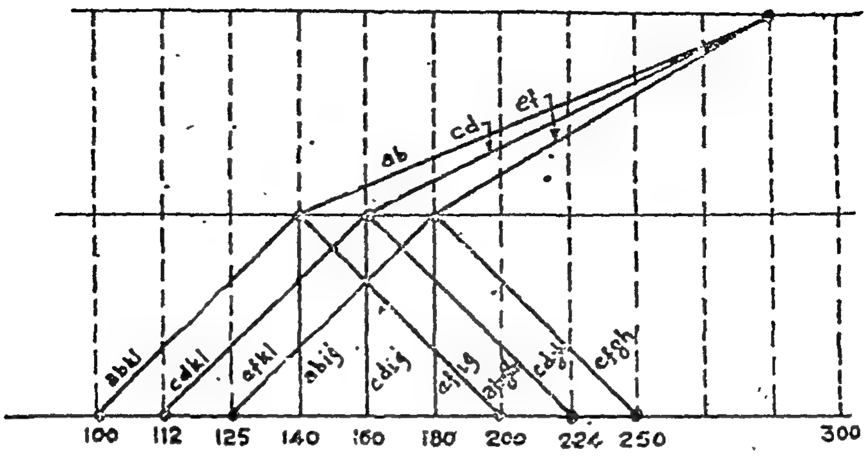


Fig. 7·08 (*b*)

Referring to fig. 7· 08(*b*)

$$\frac{\text{RPM of } a\ (N_a)}{\text{RPM of } b\ (N_b)}=\frac{300}{140}=\frac{\text{No. of teeth in } b\ (T_b)}{\text{No. of teeth in } a\ (T_a)}$$

$$=2{\cdot}14 \qquad \ldots(1)$$

also $$\frac{N_c}{N_d}=\frac{N_d}{T_c}=\frac{300}{160}=1{\cdot}88 \qquad \ldots(2)$$

$$\frac{N_e}{N_f}=\frac{T_f}{T_e}=\frac{300}{100}=1{\cdot}67 \qquad \ldots(3)$$

Due to the interference and space limitations the smallest gear should not have less than 20 teeth and the largest gear should not have more than 120 teeth. The module and the width of the gears in this case will be decided by the maximum torque to be transmitted, the permissible rubbing velocity and the gear material.

It can be seen that the gears on the shafts I, II and III must operate at fixed centre distance and hence they must satify the conditions given by

$$T_a+T_b=T_c+T_d+T_e+T_f \qquad \ldots(4\ a)$$

$$T_k+T_l=T_i+T_j=T_g+T_h \qquad \ldots(4\ b)$$

From (1) $\frac{T_b}{T_a}=2{\cdot}14 \simeq \frac{55}{25}$

hence $T_b=55,\ T_a=25$

$$T_a+T_b=80=T_c+T_d=T_n+T_f \qquad \ldots(5)$$

From (2) $\frac{T_d}{T_d}=1{\cdot}88$

Example 1

Obtain the six spindle speeds of turret lathe if the maximum and minimum speeds are 960 rpm. and 30 rpm. respectively.

Solution :

$$\sqrt[6-1]{\frac{960}{30}}=2$$

$\therefore$ Speeds are—30, 60, 120, 240, 480, 960

Example : *Design a gear box for a drilling machine to give speed variation between 100—250 rpm in 9 steps. The input shaft runs at a constant speed of 300 rpm and the out-put speeds are to be in geometric progression.*

$$\text{Speed range ratio}=\frac{250}{100}=2{\cdot}5$$

$$\text{Step ratio } (\phi)=\sqrt[9-1]{2{\cdot}5}$$

$$=1{\cdot}12$$

Hence the output speeds are

100. 112. 125, 140, 160, 180, 200, 224 and 250

The arrangement of gears in the gear box is shown in fig. 7·08 (*a*)

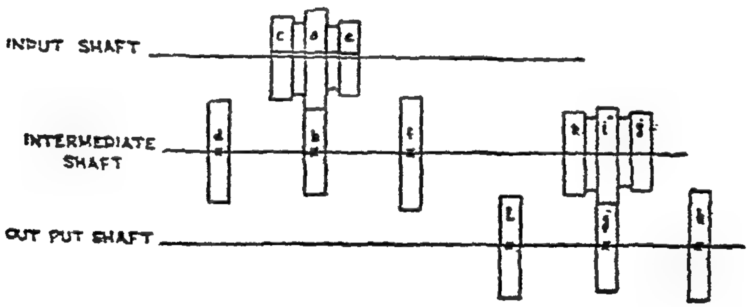


Fig. 7·08 (*a*)

The speed diagram corresponding to the gear box is shown in fig. 7·08 (*b*). The figure also shows the combinations of various gears to give the desired speeds.

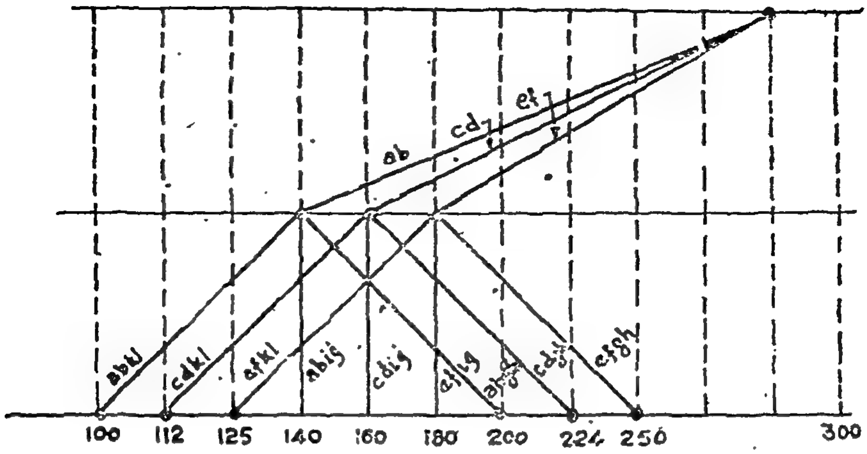


Fig. 7·08 (*b*)

Referring to fig. 7· 08(*b*)

$$\frac{\text{RPM of } a\ (N_a)}{\text{RPM of } b\ (N_b)} = \frac{300}{140} = \frac{\text{No. of teeth in } b\ (T_b)}{\text{No. of teeth in } a\ (T_a)}$$

$$=2{\cdot}14 \qquad \ldots(1)$$

also $$\frac{N_c}{N_d} = \frac{N_d}{T_c} = \frac{300}{160} = 1{\cdot}88 \qquad \ldots(2)$$

$$\frac{N_e}{N_f} = \frac{T_f}{T_e} = \frac{300}{100} = 1{\cdot}67 \qquad \ldots(3)$$

Due to the interference and space limitations the smallest gear should not have less than 20 teeth and the largest gear should not have more than 120 teeth. The module and the width of the gears in this case will be decided by the maximum torque to be transmitted, the permissible rubbing velocity and the gear material.

It can be seen that the gears on the shafts I, II and III must operate at fixed centre distance and hence they must satify the conditions given by

$$T_a+T_b=T_c+T_d+T_e+T_f \qquad \ldots(4\ a)$$

$$T_k+T_l=T_i+T_j=T_g+T_h \qquad \ldots(4\ b)$$

From (1) $\dfrac{T_b}{T_a} = 2{\cdot}14 \simeq \dfrac{55}{25}$

hence $T_b=55,\ T_a=25$

$$T_a+T_b=80=T_c+T_d=T_n+T_f \qquad \ldots(5)$$

From (2) $\dfrac{T_d}{T_d} = 1{\cdot}88$

Combining (2) and (5)

$$T_d=52$$

$$T_c=28$$

Similarly $T_e=30$

$$T_j=50$$

Also $\frac{N_k}{N_l}=\frac{T_l}{T_k}=\frac{140}{100}=1.4$ .. (6)

$$\frac{N_i}{N_j}=\frac{T_i}{T_i}=\frac{140}{100}=1{\cdot}2 \quad . \ (7)$$

$$\frac{N_g}{N_h}=\frac{T_h}{T_g}=\frac{140}{200}=0{\cdot}7 \quad .. \ (8)$$

From (6) $\frac{T_l}{T_k}=104=\frac{35}{25}$

hence $T_l=35$

$$T_k=25$$

From (4 *b*) $T_l+T_k=T_i+T_j=T_g+T_h=60$ ...(9)

Combining (9) and (7)

$$T_j=T_i\ 30$$

Combining (9) and (8)

$$T_g=35$$

$$T_h=25$$

7·042 Stepped Regulators ;

(*a*) *Stepped Pulley Drive* :

The machine tool may obtain drive from a countershaft or from a motor situated in its bed. The spindle gets four direct speeds and four indirect speeds through back gears. Such a drive is very commonly used in some of the lathes.

Advantages :

1. Simple to attend for maintenance.

2. Less vibrations due to limited use of gears. This provides smooth running of the spindle.

Disadvantages :

1. Only a small speed range is available.
2. It occupies larger space.
3. Speed is changed by shifting the belt which is a laborious method.
4. Distribution of power is directly proportional to the diameter of pulleys.

(*b*) *Geared Drive* :

Individual geared units are fast replacing the cone pulley units in the machine tools The driving unit has a large number of gears mounted on 3 or more shafts. The spindle speeds are obtained by sliding and meshing the gears by control levers for different combinations. The driving shaft of the gear box is connected to the motor at the base by means of a series of V-belts.

A chart is fixed near the control levers which shows the position of levers and corresponding speeds.

Advantages :

1. The unit is quite compact,
2. The setting of speed by means of control levers and the chart is much easier.
3. The unit is housed in a closed chamber and hence very safe in use.
4. The loss of speed is minimum and hence offers better efficiency.

Disadvantages :

1. The speed change-over can not be done while machine is ruuning.
2. The shifting of levers is difficult.
3. Friction losses are larger.

(c) *Norton's Mechanism :*

The motion from the driving shaft I is transmitted to the driven shaft through a throw-on pinion and an intermediate gear. The gears on the driven shaft are all fixed. fig. 7·09

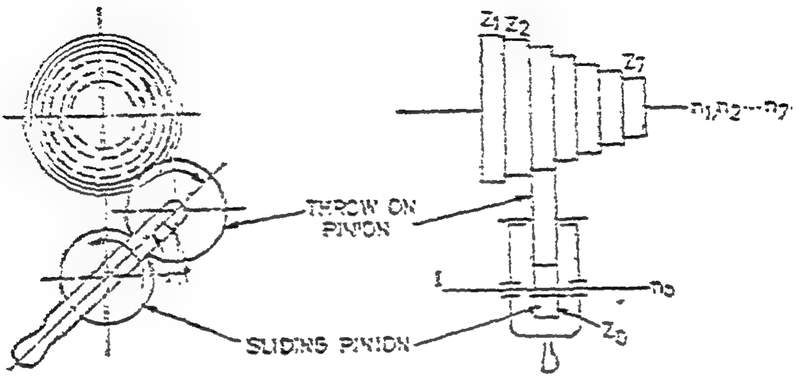


Fig. 7·09 Norton's Gear Box

Advantages :

1. The gear box is very compact due to arrangement of gears.
2. Only those gears are in mesh which transmit the torque.

Disadvantages :

1. The rigidity of the unit is not high and therefore, it is only suitable for transmission of smaller torque.
2. The shifting is difficult due to movement of the lever and gear meshing.

Norton's type gear box is used particularly for various feed boxes where lower r.p.m. are required.

(d) *Meander's Mechanism :*

It differs from Norton's gear box in that all the gears are in engagement. Hence, they rotate continuously although they are heavily or lightly loaded according to the tapping point. This fact gives unfavourable effect. The gear box offers larger speed range than Norton gear box. It should be noted that in this case instead of a single pair of gears for producing several transmission ratio, many

pairs have been arranged in series fig. 7·10. Various speeds available are :

$$n_1=\left(\frac{Z_1}{Z_2}\right)^2 n_o \qquad n_4=\left(\frac{Z_1}{Z_2}\right)^{-1} n_o$$

$$n_2=\left(\frac{Z_1}{Z_2}\right)^1 n_o \qquad n_5=\left(\frac{Z_1}{Z_2}\right)^{-2} n_o$$

$$n_3=\left(\frac{Z_4}{Z_2}\right)^u n_o \qquad n_6=\left(\frac{Z_1}{Z_2}\right)^{-2} n_o \text{ etc.}$$

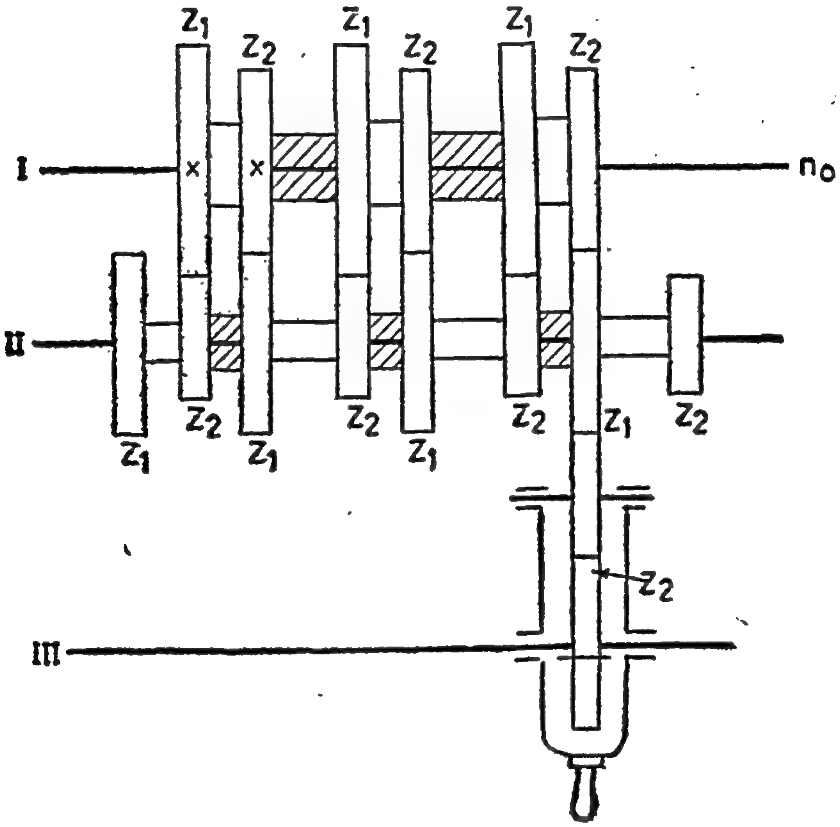


Fig. 7·10 Meander's Gear Box

The speeds are in G.P. with ratio as$\left(\frac{Z_1}{Z_6}\right)$

It is frequently used for feed boxes.

(*f*) *Sliding Key Type Gear Box* :

All the gears run idly on the driven shaft. Any one of these can be connected to the shaft by a draw-key. The key is operated by means of a hand lever. fig. 7·11.

Advantages :

1. If offers a very compact unit.
2. They use of intermedlate gears is eliminated.

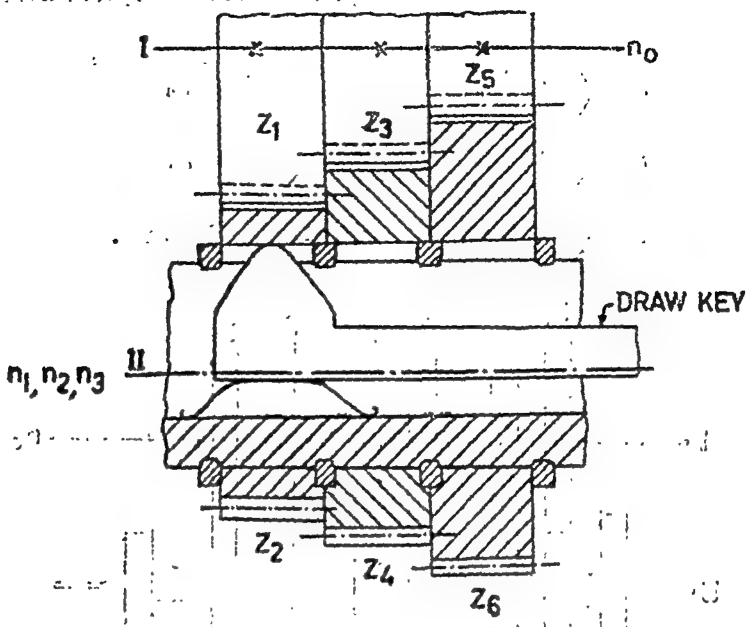


Fig. 7·11 Sliding Key Type Gear Box

Disadvantages :

1. The key can not withstand larger load and hence, used for relatively smaller loads and torques.

Frequently used in the feed box of drilling machine.

5·043 Stepless Regulators :

1. Belt Type Variator
2. Svetozarov's Variator

1. Belt Type Variator :

The variation in speed is obtained by shifting the belt on the cones. The transmission ratio is given by d_1/d_2 which is never constant. It is shown in fig 7·12.

Advantage :

The change in speed can be had without stopping the machine.

The shifting of the belt is not difficult.

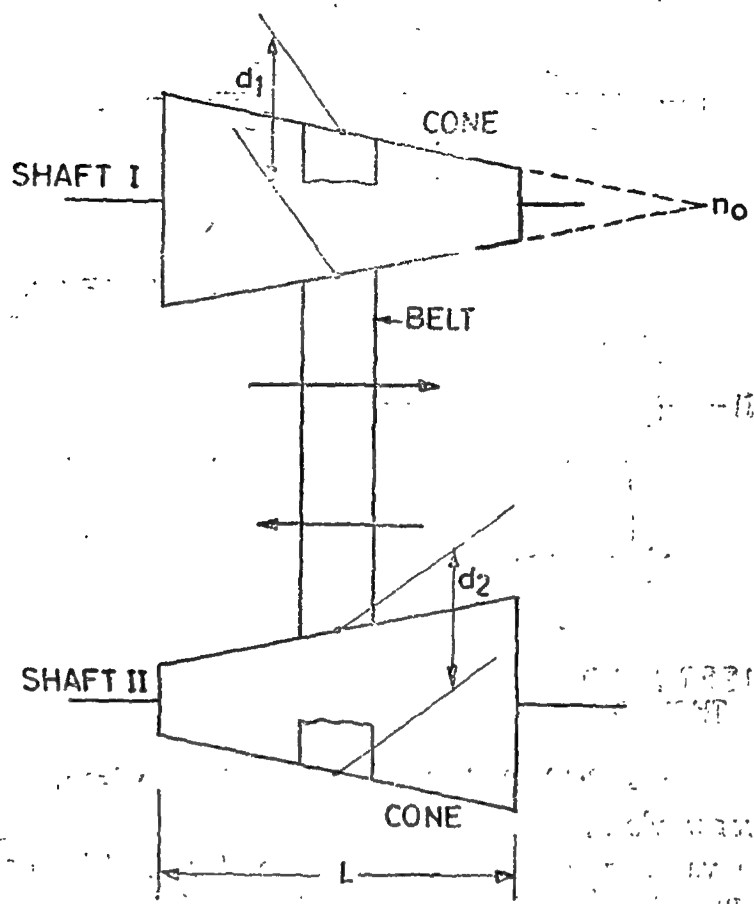


Fig. 7·12 Belt Type Variator

Disadvantage :

The belt shall start slipping if half of the cone angle is greater than the friction angle.

Usually the cone angle is 10°.

Because of lower stiffness of the belt, the unit is not suitable for large power transmission.

(*b*) *Belt type Variator with Adjustable Pulleys* :

The shifting of belt is attained by moving the pulleys in or out with the help of a hand wheel and lead screw fig. 7·13 The lead screw has both types of threads *i.e.*, left hand and right hand. The belt is stiffened by placing wooden cleats on it.

This type of unit possesses the advantages and disadvantages of the above type variator. However, this is a better device since it can transfer larger power by virtue of increased stiffness of the driving belt.

A modification of this drive is chain type variator which is commercially known as P.I.V. variator.

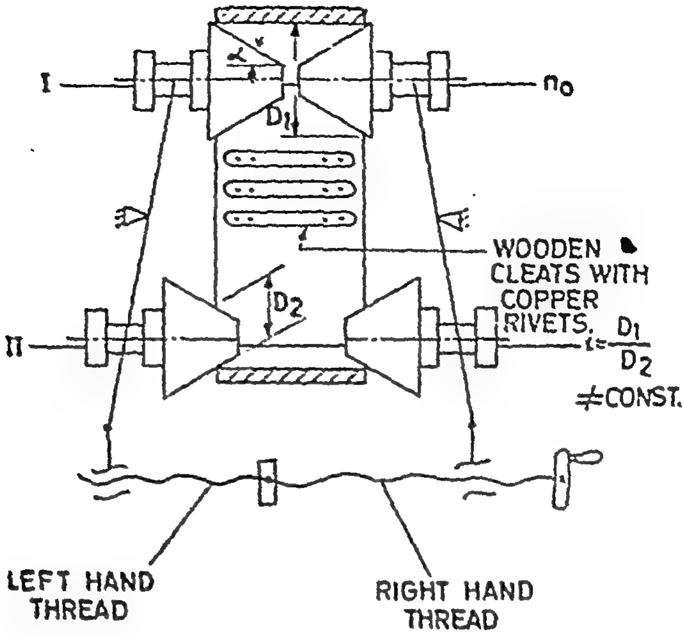


Fig. 7·13 Adjustable Pulley Belt Variator

(c) *Svetozarov's Variatar :*

The variator consists of a drive pulley a driven pulley and two cylindrical rigid discs fig. 7·14. The motion from driver is

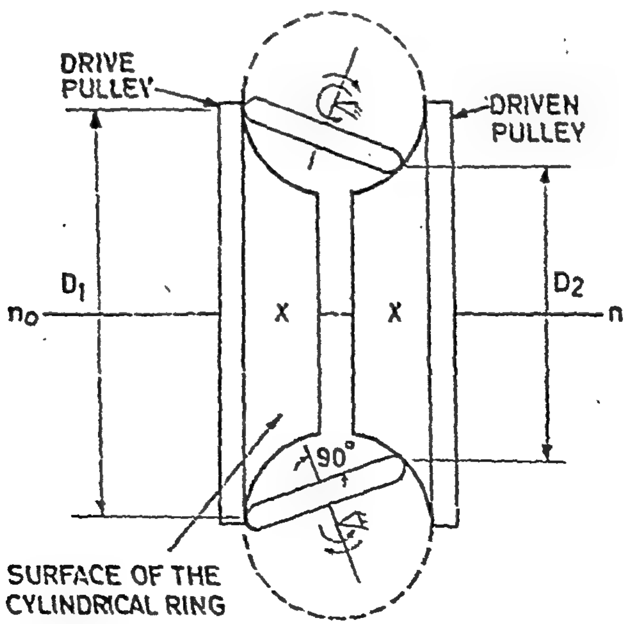


Fig. 7·14 Svetozarov's Variator

transmitted to the driven through these two discs. Any change in the inclination of these discs causes a change in the value of D_1 and D_2 which is responsible for the variation in the speed, The range of speed regulation is 10.

7·05 HYDRAULIC REGULATION IN MACHINE TOOLS

Some of the modern machine tools are now equipped with hydraulic transmission system. The motion of the ram, table or tool is controlled very effectively by hydraulic pressures and the operation is always very smooth. It offers several advantages.

1. The mechanism is simple in construction the unit is light and compact.
2. The control of rate of flow and the pressure is quite easy.
3. It offers stepless regulation of speed and feed over a wide range. The change may be had even when the machine is in operation.
4. Since there are less number of moving parts the inertial forces and moments associated with the mechanism are quite low. Thus the system operates very quitely with high efficiency.
5. The power consumption is quite low since the moving parts are less.
6. In the reciprocating type machines, it is possible to have reversal of motion instantaneously and without any damage The use of safety valve, relief valve and pressure gauge in the hydraulic line ensures further safety.
7. All the moving parts always receive lubrication.
8. The hydraulic unit need not be located just in the vicinity of the moving member as in the case of mechanical drives. It could be placed at any convenient place.

Disadvantages :

1. A major problem associated with hydraulic system is the leakage of the fluid. When the amount of leakage increases the load carrying capacity of the unit reduces and the efficiency goes down.

2. Sometimes, air pockets get formed in the hydraulic lines which makes the movement of table, ram etc. non-uniform change.
3. There are several bends in pipe's cross section which is associated with frictional losses. This further makes the system less efficient.
4. Temperature, viscosity and compressibility are a few other factors that adversely affect the performance of the system.
5. Hydraulic system is not very rigid

Hydraulic Drive Unit for Rotary System :

An electric motor (1) operates a vane type hydraulic pumps, (2) through a set of gears. The pump sends the fluids from the reservoir to a hydraulic motor (3). The motor is connected to the machine tool spindle (4) and provides rotary motion to the spindle. The regulation of the hydraulic motor is carried out by changing the eccentricity (e) of the pump which regulates the quantity of oil discharge. (fig. 7·15)

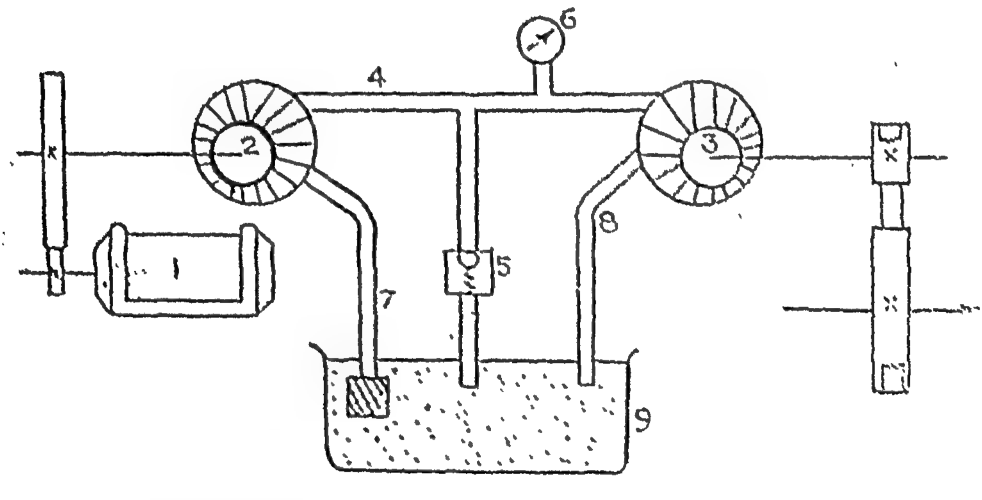


Fig 7·15 Hydraulic drive unit for rotary system

7·06 ELECTRIC REGULATION IN MACHINE TOOLS

An a. c. motor is the most popular form of an electric drive. In some of the machine tools, variable speed electric motors are also being used though their motions are less smooth and the response less rapid. A very common type of electric drive that is used on machine tools is known as 'Ward Leonard Drive'.

Ward Leonard Drive

Ward Leonard drive unit is a D.C. motor generator drive unit which is extensively used in planing machines since it can meet all the conditions of the drive in a planing machine. Some of these conditions are :

1. the drive must provide reciprocating motion to the table.
2. Infinitely variable speed must be available to have optimum cutting speed for a given tool.
3. the travel rate provided should remain constant even under full load so that cutting performance is not disturbed, severely increased by table speed drops which might even give rise to damage to tooling.
4. Drive efficiency must be high.
5. Acceleration and deceleration capacity must be adequate to ensure that reversing times and overrun distances are kept down.
6. Over run distances must only deviate slightly. Unless this demand is met it would be impossible to plane up against workpiece shoulders.

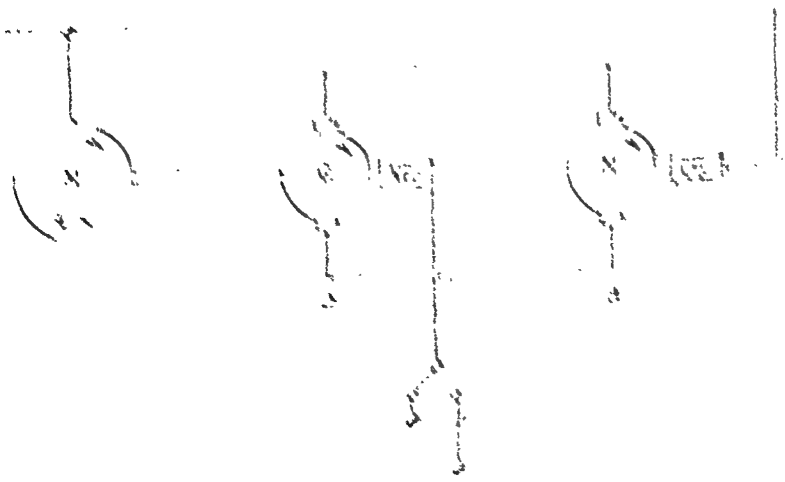


Fig. 7.18 Ward Leonard Drive

The 3 phase A.c motor (1) drives a generator (2). The generator produces a D.C. Voltage, the level of which is proportional to excitation strength and the polarity of which depends on excitation direction.

2. Sometimes, air pockets get formed in the hydraulic lines which makes the movement of table, ram etc. nonuniform change.
3. There are several bends in pipe's cross section which is associated with frictional losses. This further makes the system less efficient.
4. Temperature, viscosity and compressibility are a few other factors that adversely affect the performance of the system.
5. Hydraulic system is not very rigid.

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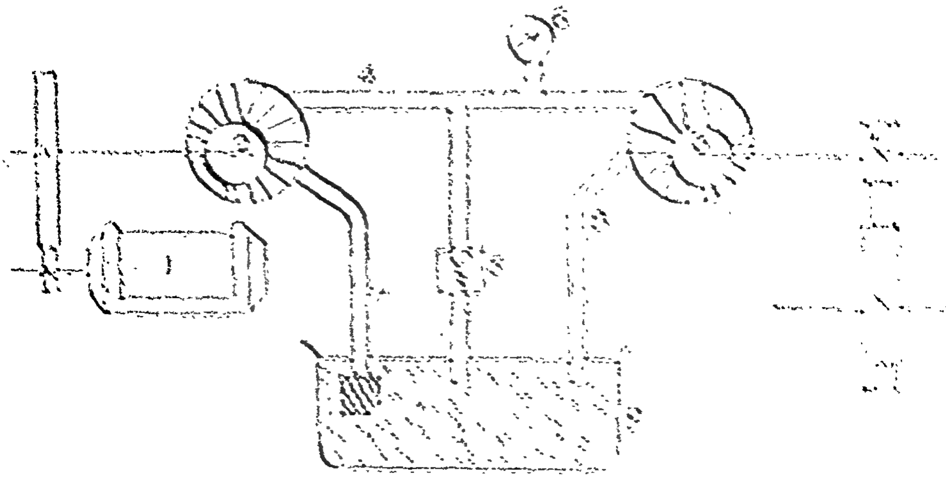

Fig 7.13 Hydraulic drive unit for rotary system

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QUIZ

1. Define a machine tool.
2. Why a box section is considered to be best for beds and columns.
3. Compare cast structure with welded structure.
4. What are the four fundamental types of slides ?
5. State some considerations for designing slideways.
6. Why machine tool spindles should possess high stiffness ?
7. Distinguish between a ray diagram and speed diagram.
8. Why the speeds are arranged in geometric progression ?
9. Name a few hydraulically controlled drive units in machine tools.

CHAPTER 8

TOOL LAYOUT FOR TURRETS

Turret and capstan lathes have been designed for machining workpieces on a rapid rate. The machining rate is greatly increased by reducing (i) the loading unloading time of the workpiece, (ii) the tool changing time and (iii) the use of a variety of tools for specific operations on these machines. Some of these specific tools are supplied with the machine tools as standard accessories whereas others can be procured separately, since these are special tools designed for particular job and machine tool. Due to this fact the quality of work depend very little on the skill of the operator. The chief work involved while using this family of machine tools is the selection of standard tools, designing of special tools, selection of feeds, speeds, tool travel etc. and this is all done well before starting the production. Such a planning and preparation on turrets and capstans is termed as tool layout and it consists of three steps.

1. Planning stage *i.e.* preparation of operation sheet.
2. Sketching of the workpiece in the various stages of machining in sequence.
3. Layout of the tools.

The machine tools are set up by the setters with the help of these tool layout sheets. Trial runs are made by the setters and adjustment are made to get the specified accuracy. The procedure for tool layouts of turrets and capstans can be described in detail as below :

1. Determine the machine to be employed.
2. Determine the operation sequence.
3. Determine the tools to be employed *i.e.*, cutting tools, special tools and standard tools.
4. Establish the cutting speeds and feeds that may be permitted.
5. Determine the time per piece.

6. Draw the drawings of the workpiece in differents stages of manufacture along with turret tools and cross slide tools in position. It may be one drawing showing all the tools on the turret or several drawings one for each operation.

First six steps of the layout can be recorded either on a plain paper or on a simplified process plannnig sheet called Operation Sheet. Before doing the actual layout the tool designer must become familiar with the turret family of machines and the variety of equipment available on them.

8:01 CHARACTERISTICS OF TURRET LATHES

Turret lathes differ from ordinary lathe in that they have no tailstock to support the work. Instead, there is a turret holding the tools which can be indexed to bring any tool in the working position. Further the cross slide of a turret is equipped with two tool posts. Front tool post is a square tool post which can hold 4 tools where as the rear tool post can hold one tool only. Turret has the capacity to hold tools which cando the operations such as turning, boring, drilling, reaming, tapping and screwing. The two tool posts on cross slide can be equipped with tools to perform the operations of facing, forming knurling, chamfering, recessing ond parting off. Cross slide and turret tools can work simultaneously with a proper tool layout planning. Longitudinal movement of the turret is controllable with the help of six adjustabe screws and so the travel of the tool performing the operation can be checked at any predetermind position even though the spindle is rotating.

The motions in a turret lathe may be classifieds as working and auxiliary motion. The spindle rotation, feed motion and cross travel are working motions. The auxiliary motions include-indexing of the turret, feeding out and clamping the bar stock and rapid traverse of turret and cross slide.

8·02 DIFFERENCE BETWEEN CAPSTANS AND TURRETS

Both capstan and turret may be commonly called turrets However, they can be differentiated easily by noting the movement of the turret head. In a capstan the turret head is mounted on a slide or ram which moves back and forth for a short length either manually or automatically. The ram guide is further set on a saddle which can be locked on the bed at any place. Thus the movement of the turret for a fixed position of the saddle is very short but the position of the saddle can be changed and locked again to suit different jobs.

In case of turrets the actual turret head is mounted on the saddle directly which moves manually or automatically whenever a tool is to be fed into the work, over the whole length of the bed. Indexing in both cases is done by the operator. Turrets are heavier machines than capstans and are therefore suitable for medium and heavy work. Both the machines can be of a design either for bar stock work or chucking operations for forgings and castings.

8.03 MAIN UNITS OF TURRET

Turrets : All modern turrets have easily operated clamping and indexing movements. These generally consist of a convenient handle or lever which, with a single to and fro motion, unclamps, accurately indexes and reclamps the turret. Mainly, the turrets are hexagonal. Some are solid except for the holes into which the tool shanks are fastened. Others are hollow with provision for bolting tools on the turret face. The advantage of hollow turret is that it permits the attachment of very heavy tools.

Apart from the hexagonal turret for longitudinal travel, the front tool post also carries a square turret which can hold four tools. A tool can be brought into working position by unclamping indexing and reclamping. The position of the tool post on the cross slide can be changed if desired.

Headstock : The headstock contains the spindle and the change speed gears. The nose of the spindle may be fitted either with a collet

chuck holder for bar stock or a three jaw chuck to hold forgings or castings of uniform size. Some turrets are equipped with a preselecter. This enables the speeds to be selected and set up for a run. The actual changing of the speeds is then quickly and accurately accomplished by the simple tripping of a lever. The feeds and speeds for general guidance for various operations are selected from a table. The feeds and speeds depend upon the kind of material to be cut, the cutting tool material and the operation to be performed. The best selection is based upon chip colour. Chip should not turn blue. Correct feeds and speeds can be seen from the plate chart mounted on the head stock cover. Turrets are rigid machines and they are run at high speeds and feeds if sufficient coolant is used to cool the stock, tool and chip. A thick stream of fluid carries away the chip also if brittle material is being machined. If the material is ductile the chip does not break away so easily but the coolant serves to lessen the friction between the chip and tool face.

8.04 TOOLING EQUIPMENT FOR TURRETS

The tooling equipment on turrets can be classified into three categories :

1. *Work holding devices.*
2. *Cutting tools.*
3. *Tool holders or tool heads.*

Work holding devices : Collets and chucks are used to hold the job in turret machines. Collets are used for accurate work of bar stock type. There are two types of collets, push out collets and pull out collets. Push out collets are mostly used because they permit the stock to be accurately fed against a stop and tightening is done in no time by the movement of lever on the collet head. Chucks used for holding bigger diameter work in the shape of forgings and castings are also fast acting chucks, either of wrenchless type, air operated or automatic type. The ordinary three jaw chuck takes too much time whereas wrenchless chuck is operated with the help of a hand lever which operates a cam which in turn moves the jaws. For certain type of work even four jaw chuck may be used because the shape of job is the deciding factor then.

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Cutting tools : The operations of turning boring, facing, and parting off are performed by cutting tools which can be forged to the required shape for use on turret tool holders or toolposts or tool heads which are available with the machine tool also. These are standard stellite tipped cutters. The other type of cutting tools are the drills reamers, taps and dies or chasers.

Tool holders and toolheads : The manufacturers have designed standarised set of such tooling equipment for use on turret lathes. These are for wide variety of set ups. A skilled operator canmake use of these tools according to his experience. There are two groups of the standardised set. (I) universal chucking equipment and (II) universal bar equipment. First type of equipment is used to process forgings, castings and similar work. Second type of equipment is designed for use on round bar stock work only.

List of Universal Chucking equipment :

1. *Adjustable single turning heads* for turning and boring. Boring is done by fixing a boring bar in the centre hole. Turning tool holder is fixed in the vertical slide hole. Bigger hole is for piloting. Vertical slide is accurately controlled by a gradrated scale.
2. *Reversible adjustable angle cutter holder.* They are for use on turning heads.
3. *Two reversible straight and angle cutter holders.* They are also for use on turning heads.
4. *Overhead pilot bar and overhead pilot* attachment to increase the rigidity of multiple turning heads by connecting these with the machine.
5. *A pair of slide tools.* It is like the turning head. It can also hold two tools. Boring bar in the upper hole which is in a slide movable from top. Recessing operations can be carried. on the inside by the movement of slide outwards. Lower hole which can be brought into centre line of spindle is used to hold drills and reamers etc. Such a

cutting where two or more operations are being performed by mounting tool on the turret head is called *multiple tooling*. It means the taking of more than one cut from the same station. If the two or more cuts from two different stations such as from the hexagonal turret and the slide are taken it is called *Combined Cutting.*

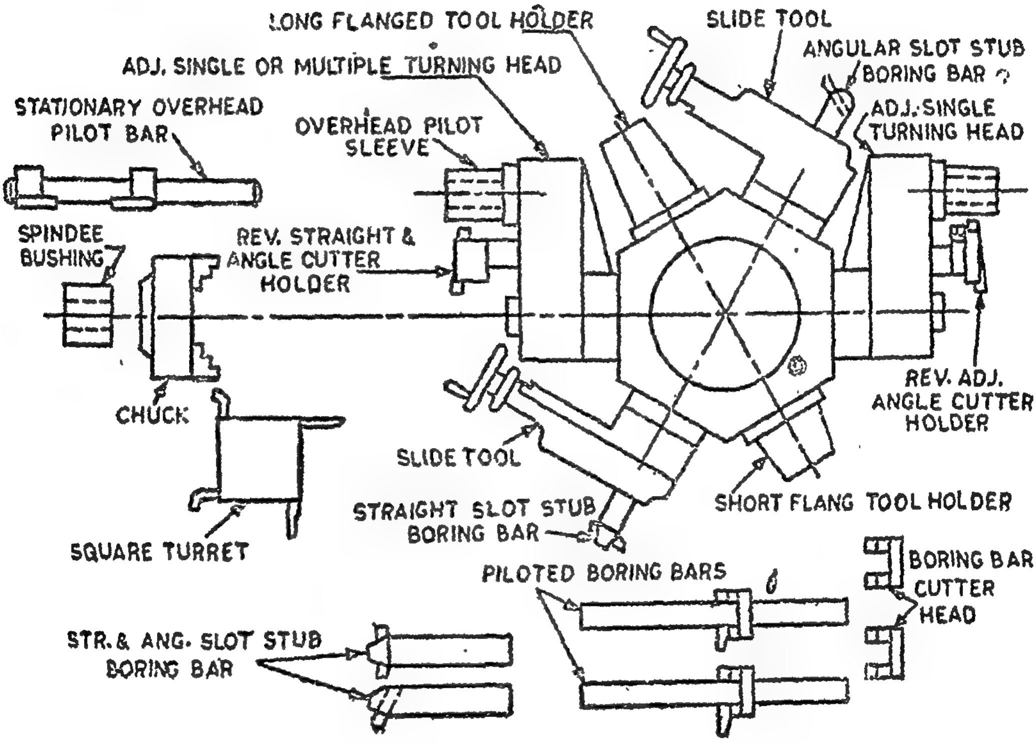

Fig 8.01 Universal chucking equipment in position

6. One set of *straight cutter stub boring bars.*
7. One set of *angular cutter stub boring bars.*
8. One short and one long tool holder.
9. Two piloted boring bars and spindle pilot pushing.
10. A set of four forged cutters for use on cross slides.

The equipment mentioned above is shown in position on the machine in fig. 8·01.

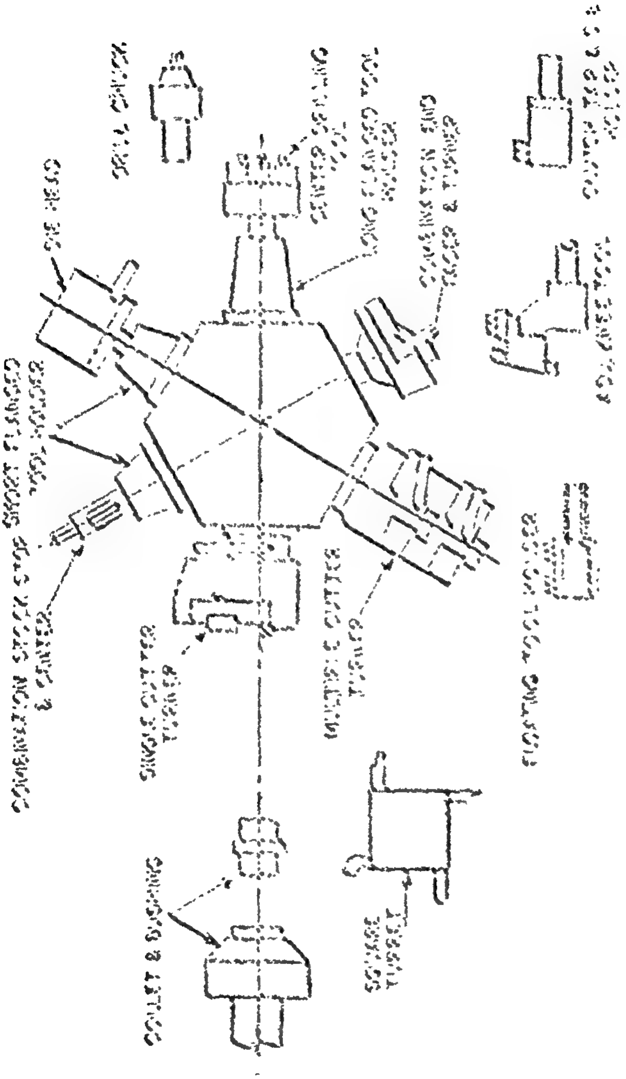

Fig. 2·92 Universal Bar equipment in position

List of Universal Bar equipment :

As it is possible to turn several stepped diameters on bar stock the equipment is designed keeping the principle of multiple cutting in view. Multiple cutter turner is an important piece of equipment for round work.

1. *Single cutter turner.* The two rollers to counter act the radial force trying to deflect the work make it a rigid tooling equipment.
2. *Multiple cutter turner.* One to four cutters can be mounted to turn different diameter steps. The rollers support the work piece. Position of the rollers can be changed to suit the work.
3. *Combination end facer and turner.* Apart from turner the facing tool placed on the tool holder can be moved in the transverse direction to do facing and chamfering.
4. *One centre drilling tool.* The rolls which can be opened and closed by knurling knob centres the work before the centre drill starts working. The rolls can work as steadies also.
5. *Drill chucks.*
6. *Combination stock top and centre.*
7. *Adjustable knee tool holder* for combined turning and drilling. Drills, boring bars or reamers can be mounted the centre hole.
8. *Short and long flanged tool holders.*
9. Self opening die head furnished with various types of removable chasers.
10. One centre.
11. A set of five forged cutters for use on transverse slides.

The above equipment is shown in position in fig. 8·02.

Example :

Prepare a tool layout for the component shown fig. 8·03 Prepare the operation sheet and also the sketches of various tool setups.

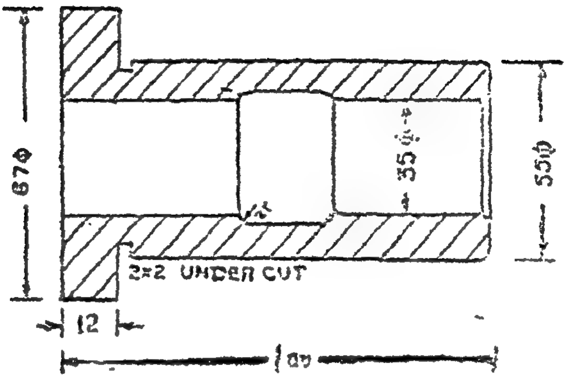

Fig. 8·03

Operation sheet for turret tooling

Machine : A turret lathe with universal chucking equipment.

Operation no.	Slide	Description	Tooling equipment
1.		Feed against stop and grip	Stop
2.	Sq. Turret	Facing operation	Facing tool
3.	Hex. Turret	Centre drilling operation	Centre drill in stop.
	„	Drill $1\frac{3}{4}''$ and rough turn to 2.885 dia length 4.250″	Multiple turning head and tools.
5.	Hex. turret	Rough bore and rough turn to 2.260 dia, length 3.213″	Multiple turning head
6.	„	Finish bore and give recess	Slide tool
7.	„	Champer with drill	Chamfering drill
8.	Hex. Turret	Turn to 2.207 dia, length 3.213″	Slide tool
9.	Sq. turret	Face and provide under cutt	Parting off tool
10.	Rear slide	Part the job with parting off tool	Parting off tool

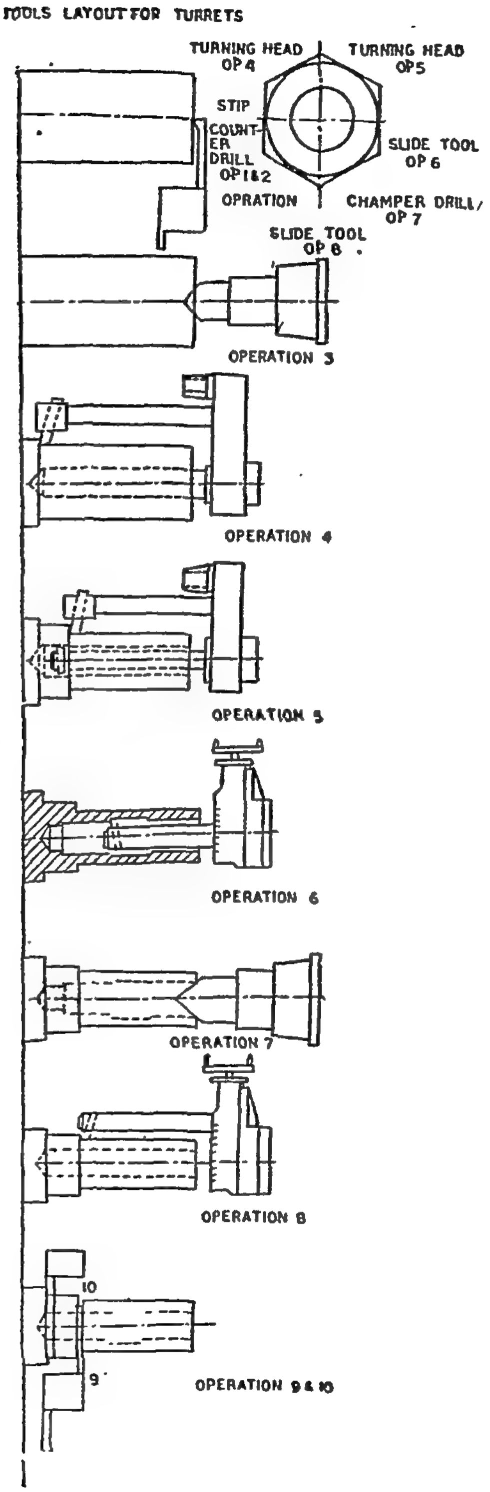

Fig. 8·04 Tool layout for M.S. Bush

QUIZ

1. Why turret and capstan lathes are suitable for production shops ?
2. What is the advantage of using a hexagonal head over a circular head ?
3. State the factors which distinguish a turret from a capstan.
4. Describe the functions of following.
   (*i*) Pilot Bar.
   (*ii*) Adjustable knee-type turning tool holder.
   (*iii*) Multi tool holder.
   (*iv*) Bar feeding device;
   (*v*) Stops.
   (*vi*) Slide Tool holder.
   (*vii*) Box tool.
5. What is a form tool ?
6. How indexing is achieved ?
7. How is a turret different from an engine lathe ?
8. Prepare a tool layout for a 15mm hexagonal nut.

CHAPTER 9

TOOL LAYOUT FOR AUTOMATS

Automats form yet another class of lathes in which all the motions required to finish off the workpiece are done automatically. How ever if the machine has to be stopped for the purpose of loading and unloading the workpiece at the end of the working cycle, it can be called a 'semi-automat. It is small in size and capacity. These kinds of lathes are special purpose machines which are only meant for making workpieces of similar nature continuously over a long period. Whenever there is a change in the job this can be undertaken. On the same machine by changing the driving cams and the sequence of operation of tool slides. The stock is also fed automatically. Because of automatic running of the machine one operator can look after more than one machine. At times he is also entrusted the work of inspecting the products on the machines. Recently some of the automats with in process gauging devices have also been developed.

9·01 CLASSIFICATION OF AUTOMATICS

Automatics can be clasified as to their size, type of blank machined, procesing capacity (operations performed), the machining accuracy attained, principle of operation, design features, number of spindles and work positions. Two main types of automatics are 1. Single spindle automatics 2 Multi-spindle automatics.

Multi-spindle automatics may have two to eight spindles Their production capacity is higher than than that of single spindle machines but their machining accuracy is somewhat lower.

Single spindle automatics are designed for various types of machining operations and can be classified further into th re distinct categories

1. Automatic cutting off machines.
2. Swiss type automatic screw machines.
3. Turret type automatic screw machines.

Automatic cutting off machines.

These can produce short work pieces of simple form by making use of tools mounted on the cross slides. Two cross slides are located on the bed at the front end of the spindle. The head stock with the spindle is mounted on the bed. Cams on a camshaft actuate the working movements of the cross slides through a system of levers. Special one, two and three station attachments are used for machining holes and cutting threads on these machines. Cross slide tools can perform the operation of facing, form turning, chamfering, and cutting off.

Swiss type automatics

They are the machines with movable head stocks and fixed tools and are known as sliding head machines also. They are designed for machining long accurate parts of small diameters (2 to 25 mm.) These type of machines employ the bush turning method. The bar stock is fed forward by a moving head stock against a stationary tool. During the process the bar stock is supported by a guide bush or steady rest set close to the working edge of the cutting tools. Overhang is therefore reduced to a minimum and as a result the work can be machined to very close limits. A wide variety of formed surfaces may be obtained on the work piece by coordinated alternating or simultaneous travel of the head stock which provides the longitudinal feed and the cross slides which provide the depth of cut. Holes and threads are machined by attachments similar to those used on automatic cutting off machines. Both the cutting off machine and the swiss type machine do not emply any indexing turret head at the other end of the bed. Cams mounted on the camshaft contaol the movent of the cross slides in both cases. The cams are designed individually for each job and mounted on th camshaft. A swiss type automatic consists of four major parts.

1. The sliding head through which the bar stock is passed and gripped by a collet.

2. The tool bracket supporting five tool slides and a bush for the bar stock.
3. The camshaft, controlling and synchronizing bar stock and cutting tool movements.
4. Auxilliary attachments for performing various operations such as drilling, tapping screwing and slotting

Cam design for the cross slide movements is the important phase of tooling up these automatics. However as there is no lead cam for movement of the turret as in turret type automatic screw machines the procedure of designing a cam is not so complex in swiss type automatics. A tool designer familiar with designing of cams in turret type automatics can be easily acquainted with designing work in Swiss type of automatics. A complete procedure of designing cams will be illustrated with reference to turret type automatics.

Turret type Automatic Screw Machines :

These are essentially automatic bar type turret lathes. They are designed for machining complex external and internal surfaces on parts made of bar stock or of separate blanks. Up to ten different cutting tools may be employed at one time in the tooling of such screw machines. The tools are clamped in the holes at the positions of the indexing turret and in the cross slides. The stationary head stock mounted on the left hand end of the bed houses the spindle which rotates in either direction. The turret slide is arranged at the right end of the bed and carries the turret having six tool holes. Two cross slides (front and rear) are provided for cross feeding tools. A vertical slide to provide additional third slide may also be employed. It is installed above the work spindle. All movements of the machine unit are actuated by cams mounted on the cam shaft. Turret slide and the three slides in combined cutting can perform the following operations on these machines : centring, turning cylindrical, tapered and formed surfacees, drilling, boring, reaming, spot facing, knurling, cutting threads, facing cutting off etc. :

Special attachments are also available for use with automatic

available in steps. Any speed provided may be obtained for any turret position and the spindle speeds are changed automatically upon turret indexing. Previously set up trip dogs consecutively engage limit switch of the electrical circuit. Some machines are provided with only a fixed number of spindle speeds both forward and reversed. However, here also the spindle speeds are changed and reversed automatically.

The spindle is mounted in preloaded radial roller bearings which prevent excessive clearance in the spindle over a prolonged period of operation. The pulley which takes its drive from the driving pulley of the motor is linked to the spindlewith a key. Spindle reversal required in thread cutting is obtained by the action of the trip dogs on a limit switch.

Drive of the auxiliary control shaft and cam shaft.

All working and idle movements of the automatic are controlled by the camshaft and auxiliary control shaft. They are driven from an individual electric motor through a worm gear. In some machines the main motor also drives the auxiliary shaft by means of a belt pulley drive. What ever may be the drive the auxiliary control shaft rotates at constant speed (120 rpm). It is located behind the bed . Ordinary tool room lathes do not have any shaft of this type. Its purpose is to carry a number of gears, cams and clutches for:

1. Advancing the bar stock through the spindle for each new piece.
2. Reversing the rotation of the spindle.
3. Indexing the turret.
4. Controlling all tool movements through lead cam and other cams mounted on a camshaft.
5. Changing the spindle speeds when desired.
6. Bringing the special attachments in position.

The auxiliary control shaft can be discharged from the driving motor by means of a hand engaged clutch. A safety with a breakable pin is also provided between the auxiliary

available in steps. Any speed provided may be obtained for any turret position and the spindle speeds are changed automatically upon turret indexing. Previously set up trip dogs consecutively engage limit switch of the electrical circuit. Some machines are provided with only a fixed number of spindle speeds both forward and reversed. However, here also the spindle speeds are changed and reversed automatically.

The spindle is mounted in preloaded radial roller bearings which prevent excessive clearance in the spindle over a prolonged period of operation. The pulley which takes its drive from the driving pulley of the motor is linked to the spindlewith a key. Spindle reversal required in thread cutting is obtained by the action of the trip dogs on a limit switch.

Drive of the auxiliary control shaft and cam shaft.

All working and idle movements of the automatic are controlled by the camshaft and auxiliary control shaft. They are driven from an individual electric motor through a worm gear. In some machines the main motor also drives the auxiliary shaft by means of a belt pulley drive. What ever may be the drive the auxiliary control shaft rotates at constant speed (120 rpm). It is located behind the bed . Ordinary tool room lathes do not have any shaft of this type. Its purpose is to carry a number of gears, cams and clutches for:

1. Advancing the bar stock through the spindle for each new piece.
2. Reversing the rotation of the spindle.
3. Indexing the turret.
4. Controlling all tool movements through lead cam and other cams mounted on a camshaft.
5. Changing the spindle speeds when desired.
6. Bringing the special attachments in position.

The auxiliary control shaft can be discharged from the driving motor by means of a hand engaged clutch. A safety coupling with a breakable pin is also provided between the auxiliary control

screw machines of this type. They provide for such additiona operations as slotting (milling slots for a screw driver in screws) milling flats, cross drilling etc.

Automatic screw machines are available in our country now a imported from various sources. They differ from each other, i minor details but here they have been discussed in a general way s that the tool designer can handle the layout of any machine with th help of the catalouge of the machine supplied by the manufacturers.

9.02 Kinematic diagram :

To give an idea of the gearing system which transmits motio to the spindle, cams and stock feeding mechanism, the kinemati scheme of an ordinary common type automatic screwing machine i given in fig. 9·01

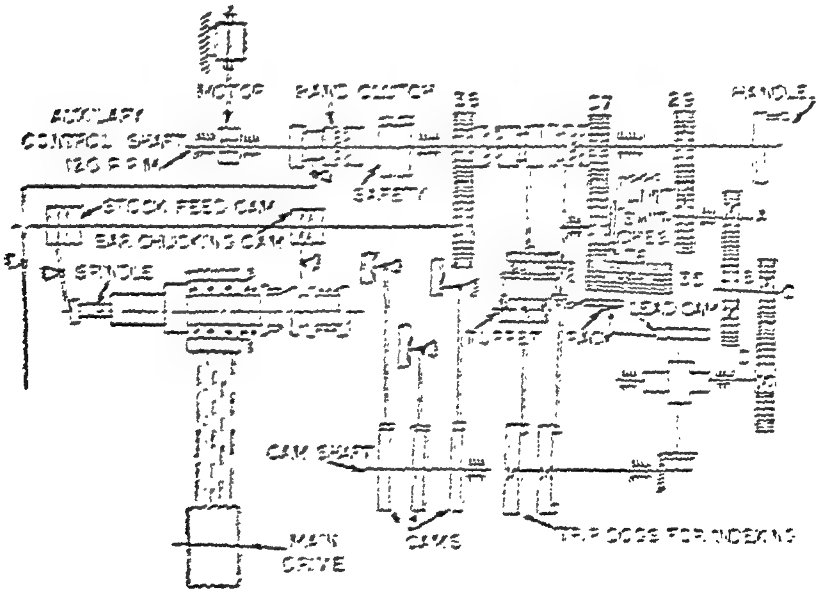

Fig. 9·01 Kinematic diagram of an automatic

Drive—The main drive is from an electric motor supplied from a converter with adjustable voltages. The main drive provides for an infinitely variable range of spindle speeds from 60 to 2000 rpm in some machines where as in others the speeds are

available in steps. Any speed provided may be obtained for any turret position and the spindle speeds are changed automatically upon turret indexing. Previously set up trip dogs consecutively engage limit switch of the electrical circuit. Some machines are provided with only a fixed number of spindle speeds both forward and reversed. However, here also the spindle speeds are changed and reversed automatically.

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5. Changing the spindle speeds when desired.
6. Bringing the special attachments in position.

The auxiliary control shaft can be discharged from the driving motor by means of a hand engaged clutch. A safety coupling with a breakable pin is also provided between the auxiliary control

shaft and driving motor. A handle on the right gives movement to the control shaft for setting operation when the motor is disengaged. Items like 36 tooth gear for giving movement to stock and chucking cam drums as well as stock stop, 57 tooth gear for driving turret rapid traverse and indexing machanism are mounted freely on the control shaft and may be engaged by separate clutches. Mechanism for these auxiliary (idle movements) are engaged and disengaged by single revolution clutches which are controlled by cams or trip dogs mounted on drums or carriers adjusted on the cam shaft.

The cam shaft is driven from the auxiliary control shaft and consists of two sections, a longitudinal section in front of the bed and transversection. The speed of the cam shaft is set up by two pairs of change gears $\left(\frac{A}{B} \times \frac{C}{D}\right)$ and can be adjusted by maniplating these gears if so desired. Lead cam (Plate cam) mounted on the tranverse camshaft section traverses the turret slide through a lever gear segment and rack. Longitudinal section of the cam shaft carries two cams to control cross slide movements. This section also carries a cam for the third vertical slide as well as drums or carriers for fixing trip dogs or cams which control the operrtion of the single revolution clutches on the auxiliary shaft through a lever system. Carriers remain constantly on the cam shaft only the trip dogs are adjusted on slots. The cams for rear and front slides as well as vertical slide can be taken out and replaced for new job.

Turret slide. The turret slide carrying the turret reciprocates along the guide ways held by screws to the bed. The turret has six tool holes. Tools are clamped in the holes by a split bushing and a binding screw. The lead cam which actuates the turret slide is located on the camshaft by a driving pin which enters a 10 mm diameter hole in the cam and thus the cam is directly positioned in reference to the zero line on the other cams or trip dogs or carriers. Actually all cams are located in a similiar way so that zero lines coincide. The turret slide is retracted by a spring inside the slide. The turret

is automatically indexed and locked in position by the action of the auxiliary control shaft when desired. Indexing can take place at any point during the travel of the turset slide, When the turret is indexed it suddenly moves back a little, than only indexing takes place and after locking the turret moves forward to its original position again.

Cross slides : The cross slides travel in detachable cast iron ways secured to the bed by the screws. The travel of slide is controlled by cam-shaft through levers with segment gears. Tool posts are held by 7 bolts in the T slots of the slides.

Cooling System : A gear pump is mounted on the lower part of the rear wall of the bed. It delivers oil from the reservoir through a pipe line to the cutting tools. The mechanism of the automatic is lubricated in certain places manualy and in others by a centralised force feed system from a pump.

Stock feeding and chucking : As soon as the trip dog on carrier mounted on the cam shaft trips the lever the clutch on the auxiliary control shaft is engaged and 36 toothgear on the control shaft gives rotation to another shaft which has both the bar chucking cam and stock feed com mounted on it in the shope of borrel cams. Chucking cam controls the collect. When the collect is open and the bar stock is loose, spring finger controlled by stock feed cam grips the and pushes it ahead through the collet until the stock hits against a stop. The collet again grips the stock and higher moves to the original postion. Stock is fed independently of the other movements without stopping the spindle, but the time element to perform this operation must beallowed for in relation to the rest of the layout and speed of the machine to prevent tool collisions etc.

Special attachments :

Special attachments greately help in enlarging the field of operations that can be performed on a automatic screw machine

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Fig. 8.2. The blades can be set very easily by swinging the cutter up and down. The cutter is ground with the cutting edge

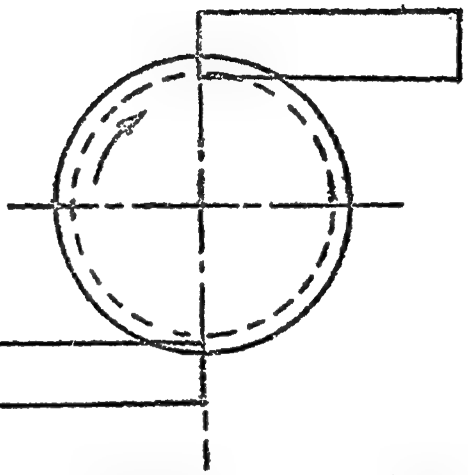


Fig. 8.2

square or perpendicular to the face of the shank. The back rake angle (from cutting edge to back of blade) is ground to 30°. This makes a setting angle of 15° for the clearance.

Box tool holders are held in the turret by their shanks. They are extensively used for straight turning and can turn one, two or three diameters simultaneously. however here also the actual cutting blade is held to cut tangentially as in balanced turning tools. The work is balanced with the help of a back rest instead of the second cutting blade. Cutting blade of a box tool is set similar to balanced turning tool. The clearance angle for a box tool is 8 degrees and rake angle should be between 15 and 40 degrees, depending upon the material to be cut.

Knee tools are used for roughing cuts. Further a knee tool due to its portion does not interfere with tools in the cross slides. Knee tool holders can be fitted with one cutting blade hence the work piece is not so well balanced.

without transferring the work piece to some other machine. Social attachments enable second operations to be performed at the same time when another component is being machined. The most important of them are the magzine feed, screw slotting attachment. high speed drilling attachment, supplementary swing stop. outside feeding attachment and bar restocking attachment. The component after being pated off is gripped in an arm and swung up to the saw which machines the slot. The burring attachment is another useful attachment. The component when it leaves the bar is taken to and held in a chuck while the operation is performed.

Standard Tools and Tooling Equipment :

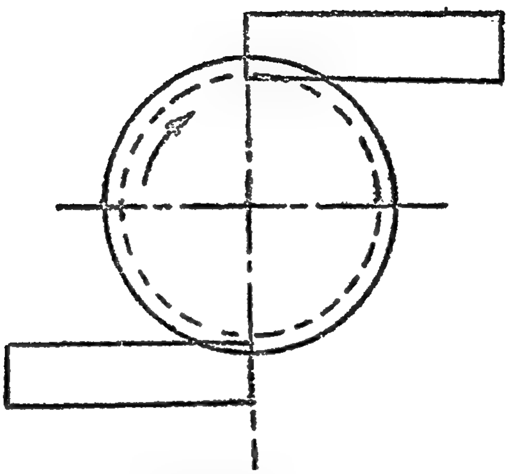
Though knowledge of standard tools and tool holders available with the machine is necessary for all tool designers. Before attempting to design the cam the tools to be used must be selecten. The drawings of these tools and toolholders to know about their ovehang etc., must be available to the tool designer. Tools available with automatics can be divided into six groups as follows :—1. External turning tool. 2. Internal cutting tools. 3. Threading tools. 6. Supporting and auxiliary tools.

External Turning Tools ;

These tools are the hollow mills, balanced turning tools, box tools, knee tools and swing tools. The actual tool bits are mounted in their respective holders to perform the operations where as hollow mill can be mounted directly in the turret hole without the intermediate tool holder. Adjustable hollow mills are similar to plain hollow mills but have inserted blades with independent radial adjustments.

Balanced turning tools consists of two cutting blades set to operate on opposite sides of the work piece and clamped securely in a box like body. The balanced turning tools are mounted on the turret. Both the turning blades and the holder comprise a balance turning tool Unlike the plain lathe turning tool which cuts radially the blades of the balanced turning tool cut tangentially.

Fig. 8.2. The blades can be set very easily by swinging the cutter up and down. The cutter is ground with the cutting edge



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The swing tool consists of swinging arm one end of which is arranged to hold a blade and the other is pivoted to a shank for holding the tool in the turret. The blade is swung into the work piece while the tool is being controlled by the lead cam to turn tapers or cut behind shoulders. Taper turning with a swing tool is accomplished with the help of a cam surface clamped to the front tool slide of the machine. This cam surface forces the tool towards the centre of the workpiece. The cam follower consists of an adjustable screw by means of which the cutting edge can be accurately positioned by the set up man. The pivot point is placed above the centre of the workpiece and the cutting edge moves about one half the distance that the follower screw moves. Thus four classes of operations can be performed by swing tool by giving movement either to turret or cross slide or both. These operations are straight turning, taper turning, form or contour turning and cutting off.

Internal cutting tools :

Drills, reamers, taps and dies are the internal cutting tools. For work in which the tolerances are not very close a simple drill holder or bushing may be used but where the hole to be drilled must be accurately centred and maintained, a floating holder is needed. For accurate work drilling should always be preceded by a centring operation. Taps and dies are also fitted in holders which are of two types, releasing types holders and non releasing type holders. Both are similar in construction the difference being that the releasing holder has a clutch which enables the tap or die to rotate once the tool has threaded to the specific length. In both cases the spindle has to reverse to enable the tap or die to return to its original position. With releasing type it is possible to thread close to a shoulder.

If the spindle cannot be reversed or it is not desirable to reverse, it is possible to cut external threads without reversing by using self opening die holders. In this, four thread chasers are thrown out automatically when the die reaches the releasing point. The chasers clear the thread as the turret withdraws and when the turret indexes, a strap on the side of the holder is brought into contact with a closing plate that is attached to the be[illegible] of the

machine. This closes the chasers, making them ready for the next work piece when the cycle is repeated.

Threads on screws and bolts can be cut by rolling also. The rolling operation consists of forcing hardened steel roller containing the thread form against the work piece in such a manner as to cause the metal to flow away from the high points of the roll and produce a thread. The hardened steel roller is held on the turret slide like a knurling tool. In ordinary engine lathe knurling tools a.e held in the cross slide but for automatic knurling, tools are held in knurling tool holders of various designs mounted on turret slide.

Circular cutting and forming tools fig. 9.3 are on the cross slides. There are three advantages to the circular shape over the convential tools.

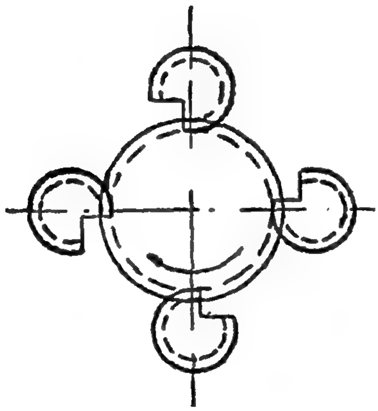

Fig. 9.3 Circular cutting tools

1. They can be sharpened by regrinding without altering the contour of the work piece.
2. The tools can be produced economically an a lathe from standard blanks.
3. The work produced is very uniform in quality and needs little checking at inspection.

Specifications of automatics :

The catalogue showing the specifications and other details are available to the tool designer before he starts tooling up the machine tool. The following details should be generally included in a tabular form for ready reference for various models.

1. Bar capacity.
2. Maximum stock feed.
3. Maximum length turned.
4. Maximum thread cut in steel.
5. Number of spindle speeds.
6. Range of spindle speeds.
7. Actual time allowed to feed stock or part of the cam in hundredths.
8. Actual time allowed to index turret or part of the cam in hundredths.
9. Diameter of turret.
10. Number of holes in turret.
11. Maximum distance tools can project from turret.
12. Maximum diameter of tools turret will swing.
13. Maximum distance of chuck to turret.
14. Minimum distance of chuck to turret.
15. Movement of cross slides.
16. HP of motor.
17. Dimensions of the lead cam and other cam blanks.

Tool layout procedure :

As already described in the previous chapter the tooling up consists of three phases 1. operation planning stage in all the columns of the operation sheet are filled up. 2. Sketching stage in which the tools are shown in the foremost position in a operation. 3. Cam design stage. Both operation planning and sketching is completed before starting to design the cams. Operation sheet for automatics is different from the operation sheet for other machines as calculations for cams are also incorporated in the sheet. A systematic procedure to fill out the columns of the operation sheet

to further draw the sketches of tool layout and then design the cams is as follows.

1. Determine the model of the machine to be employed.
2. Determine the operation sequence.
3. Determine the tools to be employed and the position in which they are to be mounted.
4. Establish the cutting speeds permissible for the material to be machined based on the operations to be performed.
5. Calculate the revolutions of the spindle per minute.
6. Determine the distance to be travelled by each tool.
7. Establish the feed per revolution of spindle for each tool.
8. Calculate the revolutions of the spindle for each cutting operation adjusting where necessary for over lapping certain operations.
9. Calculate the revolutions of the spindle for all idle movements.
10. Establish the number of revolutions of the spindle required to complete one component and correct to suit the revolutions actually available using standard change gears.
11. Calculate the hundreths of cam surface needed for both cutting and idle movements, or operations.
12. Establish the time per piece.
13. Draw the tool layout showing all distances.
14. Design the cams on blank cam sheets.

Operation Planning Considerations :

The following main rules should be followed in planning a manufacturing process *i.e.* in laying out the sequence of operations necessary to produce a piece of work :—

1. Overlap working operations where ever possible and try to increase the number of tools operating simultaneously.
2. Overlap handling operations with each other and with the working operations.

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6. Range of spindle speeds.
7. Actual time allowed to feed stock or part of the cam in hundreths.
8. Actual time allowed to index turret or part of the cam in hundreths.
9. Diameter of turret.
10. Number of holes in turret.
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2. Overlap handling operations with each other and with the working operations.

3. Overlap roughing and finishing cuts only in cases when this does not have a detrimental effect on the quality of the work piece. Finish machining should be done at the end where-ever possible.
4. Arrange the cutting tools so as to counter balance the cutting forces to the maximum extent.
5. Provide for a finish cut over the full length of a surface if it was roughed in sections by several tools.
6. Do not permit substantial reduction in the rigidity of the work piece (cutting deep grooves) until all the machining is completed. This is specially important in thread cutting.
7. Turn precision form surfaces in two cuts wherever possible.
8. Provide a dwell of 5 to 10 spindle revolutions at the end of the cross slide travel to improve surface finish.
9. Use centre drill before drilling small diameter holes.
10. In drilling deep holes pull out the drill several times to remove chips.
11. Finish machine external and internal surfaces at a single position to obtain their strict alignment.
12. See that the tools do not interfere with each other.

The tooling layout *i.e.* 2nd stage of process planning consists of sketching of the work piece in various stages of machining by operation elements. The required cutting tools are indicated and are shown at the end of feed motion.

The selection of feeds for various operations is also an important consideration. The feeds can be selected for rough from cutting with cross slide tools equal to 0.04 mm Or 0.002 inch per spindle revolution for finish forming equal ta 0.001" or (0.025 mm) per revolution and for straight turning and drilling equal to 0.12 mm (0.003" per revolution).

Time required for each operation element :

The time required for an operation element depends on 1. tool travel 2. selected rate of feed 3. number of spindle revolutions

required for the tool travel and 4. comparison of the spindle revolutions with the spindle speed in rpm. The total time in seconds is based on the total number of spindle revolutions to complete a piece if the spindle runs continuously at one speed. If in different operations different spindle speeds are employed (as for threading), it will be necessary to recalculate the number of spindie revolutions in each operation element to a single basis, dividing by the so called equivalent revolutions factors.

$$\text{Revolution required for threading or tapping} = \frac{\text{Throw in inches} \times \text{tpi} \times \text{rpm (fast)}}{\text{rpm (slow)}}$$

where rpm (fast) is speed at which spindle is rotating most of the time and rpm (slow) at which the threads are being out. During return, in tapping, revolutions required to unscrew=throw in inches $\times$ tpi.

In a self opening die, the die is made to come even faster.

Time For Idle Motions.

The time required for idle motions like indexing and feeding the stock depends on the design and type of automatic employed. Idle motion time is mostly constant as idle movements originate from auxiliary control shaft which runs at a constant speed. The idle motion times are furnished in setting up instructions of each automatib. Cams are usually divided into 100 parts and time required for idle movements is expressed in hundreds. Thus it may be specified, single or double indexing will require 5 or 6 divisions in the cam and feeding will require another 5 or 6 divisions.

The hundreth of cam for idle motions is found by a little calculation also. Revolution of the spindle for working operations are summed up. Then as spindle rpm is known the time for working movement is found out. Then estimated cycle time will be 1.1 to 1.3 times the working times. On the basis of this value, the number of hundreths required for the idle movements may be found in tables of service manual.

Example :

Prepare an operation sheet for the component shown in Fig. 19.4 of free cutting steel, complete in all respects so that it may be

used to draw the cams. Show the layout with tools in the forward most positions and design the cams.

Solution :

Operation sheet has been drawn in Table 15.1.

Total idle movements = 18 hundreths.

Actual cutting movement = 100 − 18 = 82 hundreths.

433 revolutions of the spindle occupy 82 parts of the cam.

one revolution of spindle occupies 82/433 hundreths.

Now the hundreths of cam circumference necessary to complete each operation is calculated and entered in colmn 8.

For calculation of production time per part.

82 hundreth = 433 revolutions of spindle

$$100 \;\;,, \;\;,, = \frac{433 \times 100}{82} = 530 \text{ revolution of the spindle}$$

$$\text{Production time per part} = \frac{530 \times 60}{1500} = 21{\cdot}2 \text{ seconds}$$

$$\text{cam shaft speed} = 60/21{\cdot}2 = \frac{600}{212}$$

If N_{ca} is the cam shaft speed and N_{as} the auxiliary control shaft speed then

$$N_{as} = N_{as} \times \frac{29}{79} \times \frac{A}{B} \times \frac{C}{D} \times \frac{1}{40} = \frac{120 \times 29}{79 \times 40} \times \frac{A.C}{B.D}$$

$$= 1{\cdot}1 \times \frac{A.D}{B.D}$$

$$\text{Hence} \quad \frac{A \times C}{B \times D} = \frac{60.0}{2.12 \times 1.1} = 2.56$$

The gears A, B, C and D are selected to give this ratio. The catalogue also directly provides these gears for the cycle revolutions of the spindle. If the exact spindle revolutions in a cycle are not available in the catalogue, the nearest revolutions should be assumed and necessary adjustments should be made in operation revolutions to make up the new total revolutions. The gears A, B, C and D are selected then directly from the table corresponding to cycle revolutions.

Designing of cams

Cams are designed in the following order :—

1. The main data on the cam and the leverage system to move the slides are taken from the catalogue. The data required is (*a*) maximum radius of the cam (*b*) minium radius of the cam, (*c*) height of the cam lever fulcrum above the cam centre (*d*) ratio of the lever system.

2 The surface of the cam is drawn on drawing in full scale and divided into 100 equal parts.

3. The cam radii are determined for each operation element from the final position of tools in each operation. Hence tool layout should be drawn beforehand showing tools in their foremost positions and also the tool travels or throws for each operation. Fig. 15·5.

4. For turret slide the maximum diameter of the cam blank corresponds to a slide position at the minimum distance from the spindle nose. For cross slides the maximum diameter of the cam blank corresponds to a position where the tool has advanced slightly beyond the spindle axis. In the example the toollayout fig. 19.5 shows the minimum distance between the collect face and turret face to be $1\frac{13}{16}''$ for the operation of turning. So this position corresponds to maximum cam blank diameter assumed 5″ in this case. In some machines the maximum diameter of cam gives a fixed minimum distance between chuck and turret face as specified by makers. If the minimum distancc position of the turret face during operations is different from this. then maximum cam radius for the operation in which turret face is nearest is calculated by subtracting an amount called *Cut Down* from maximum blank radius. Cut down is the difference between the fixed minimum distance for the machine and the minimum distance reached during the operations in the particular setup.

5. The radii of cam for other operations in final positions are determined accordingly. The radius of cam for threading to be completed, from the figure is$=2\frac{1}{2}-\left(1\frac{29}{32}-1\frac{13}{16}\right)=2\frac{13}{32}$ because

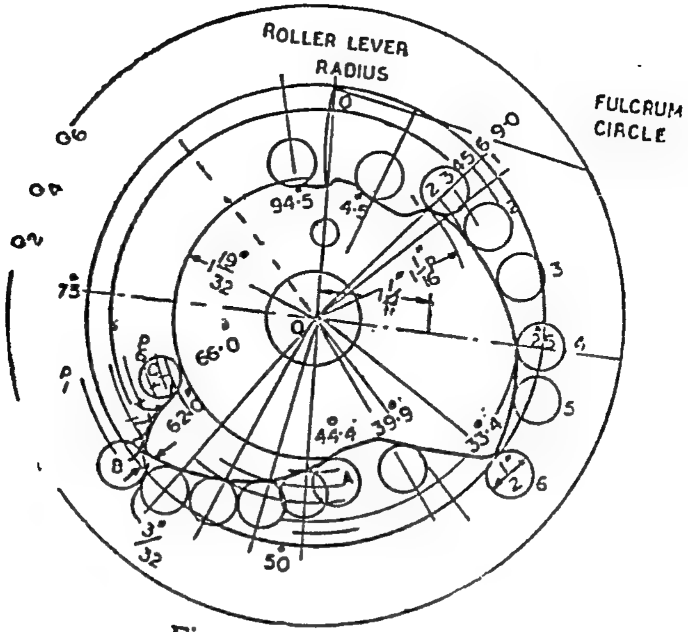

Fig. 19·6 Lead cam

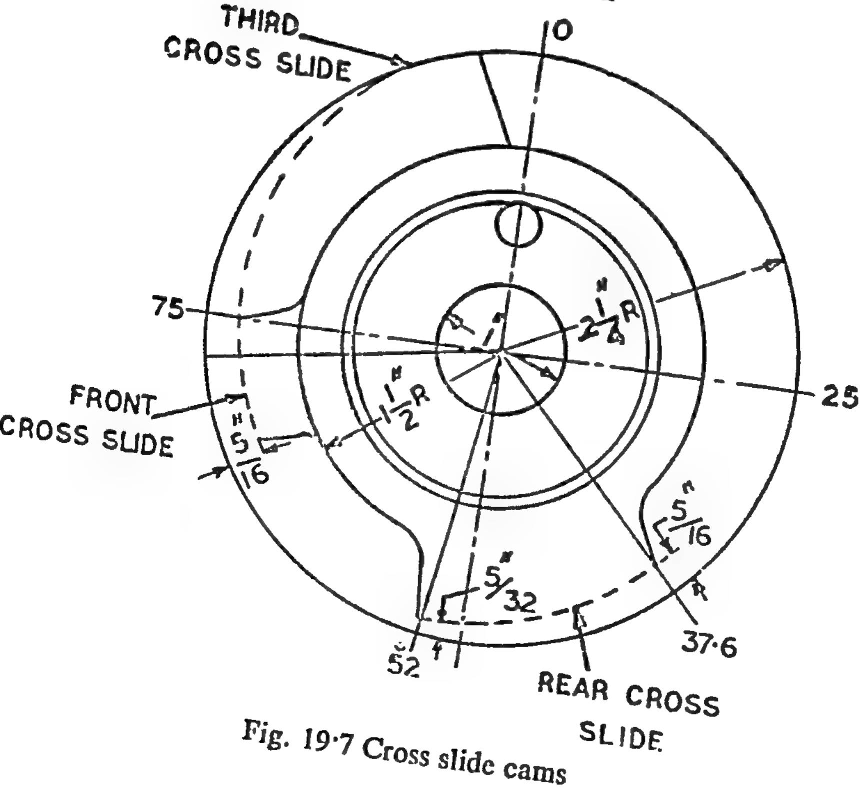

Fig. 19·7 Cross slide cams

tangency positions at the blank periphery is divided into certain number of parts marked in Roman numerals and arcs are drawn with radii equal to cam follower lever. The rise of the follower tangency points is also divided into as many parts and marked in arabic numerals. Area of circles are drawn with centre of cam as centre and radii upto the arabic numerals to cut the corresponding Roman numerals. The intersection points are the points of tangency of the follower. These points will describe a curve which will ensure a uniform feed of the tool. Figs. 19·6 and 19·7.

Thread Lobes :

The method for developing threading lobes applies to both taps and dics. The return time may be same as for threading if the spindle continues moving at the slow speed. However the return time is reduced if the spindle is switched on to fast speed. Consequently while drawing lobes the return is accomplished in the same number of hundreths as for threading if the speed is slow and in less if the speed is switched on to fast.

The threading lobe is always something less than the calculated throw say 5 percent. The ensures that the threading tool will travel a little faster than the turret and will prevent the tool being forced hard into the work piece. When the threading tool is unscrewing, 100 percent of the throw is used. This prevent the tool being held back by the turret and ensures that it will clear the component with ample float available between the tool and its holder. A threading lobe is determined in the following manner. Fig. 19·6.

From centre O draw an arc of the fulcrum circle and a second arc forming part of the cam periphery. Draw the roller of follower at the commencement of the lobe and again at the finish of the rise and fall. A, C and C are centres of the follower at the three positions. The position of the roller B at the high point of the lobe includes an allowance of minus 5% of the thread throw. The throw is thus less than theoretical by 5%. The position of C is however at the same distance as A from the centre of the cam.

Using centre O draw arcs P1 and P6 through the centres of the rollers B and C. The space between is divided into five parts. Having determined the radial distance of roller lever, strike arcs using this distance as radius to cut the fulcrum circle at Q1 and Q6. The space between Q1 and Q6 is also now divided into five parts. Using the same radius as before strike arcs P2, P3, P4 and P5. Draw rollers at positions P2, P3, P4 and P5. A curve is now drawn tangential to the rollers. This will be thread lobe for return in case of taps and dies if the die is not of self opening type.

Cams for the example are drawn is fig. 196 and 197. Each cam is represented by a different line. However they should be drawn on the same blank circle to show their relative positions. They are mounted on the cam shaft in this very position. Pin holes in the cam blank ensure this.

If a cam lobe is showing the end of the return movement or simply the cam is showing a dwell then to index at a certain point always reduce the radius of the cam for this idle movement because for indexing the turret is always thrown back and returns to its position when indexing is complete.

Cutting Speeds and feeds for Turrets and Automatics Using H.S.S. tools

Cutting speeds in Surface Meters per minute

	Brass	Free cutting steel	Mild steel tensite strength lb/□" 10"			Chromium Nickel steel
			59000—66000	74000—88000	100,000 120,000	
Turning and cutting off	120—150	60—75	35—40	25—30	20—25	18—20
Drilling	70—120	40—50	30—35	20—25	15—20	14—18
Threading	30—60	6—8	6—8	4—6	3—6	2—3

Feed in millimeters per spindle revolution for turning

Turning with box tool	.150—.250	.115—.156	.107—.155	.100—.137	.075—.107	.075—.100
Forming	.02—.05	.015—.040	.015—.035	.012—.035	.010—.030	.010—.025
Cutting	.050—.100	.035—.050	.030—.046	.025—.040	.020—.035	.020—.030

Feeds in millimeters per spindle revolution for drilling and centering

Size of drill in mm.						
2—4	,070—.010	.050—.075	.050—.075	.04—.07	.03—.05	.03—.06
4—8	.10—.15	.06—.10	.06—.08	.05—.01	.04—.06	.04—.06
4—14	.11—.17	.08—.12	07—.10	.06—.08	.05—.07	.05—.07
14—20	.12—.20	.08—.13	.08—.12	.07—.11	.06—.08	.06—.08
Centering	.17—.20	.12—.15	.10—.15	.10—.12	.07—.10	.07—.12

Cutting speeds and feeds for Turrets and Automatics Using H.S.S. tools

Cutting speeds in Surface feet per minute

	Brass	Free cutting steel	Mild steel tensile strength lb/in² 59000—66000	Mild steel tensile strength lb/in² 74000—88000	Mild steel tensile strength lb/in² 100,000—120,000	Chromium Nickel steel
Turning and cutting off	190—430	195—245	125—140	85—105	65—80	60—72
Drilling	130—330	130—165	100—115	66—85	52—65	45—60
Threading	100—200	20—30	20—26	13—20	10—16	8—10

Feed in inches per spindle revolution for turning

	Brass	Free cutting steel	59000—66000	74000—88000	100,000—120,000	Chromium Nickel steel
Turning with box tool	.006—.010	.0047—.0063	.0043—.0063	.004—.0055	.0031—.0043	.0035—.005
Forming	.0008—.002	.0006—.0016	.0006—.0014	.0005—.0014	.0004—.0012	.0004—.001
Cutting off	.002—.004	.0014—.002	.0012—.0018	.001—.0016	.0008—.0014	.0008—.0012

Feeds in inches per spindle revolution for drilling and centering

Size of drill inches	Brass	Free cutting steel	59000—66000	74000—88000	100,000—120,000	Chromium Nickel steel
5/64—5/32	.003—.0047	.002—.0035	.002—.003	.0016—.0028	.0012—.002	.0012—.002
5/32—5/16	.004—.0063	.0024—.0043	.0024—.0035	.002—.0031	.0016—.0024	.0016—.0024
5/16—9/16	.0047—.007	.0035—.0047	.0031—.004	.0024—.0035	.002—.0028	.002—.0028
9/16—13/16	.005—.008	.0035—.0055	.0035—.0047	.0031—.0043	.0024—.0035	.0024—.0035
Centering	.006—.008	.005—.006	.004—.006	.004—.005	.003—.004	.003—.004

QUIZ

1. What do you understand by tooling up of an automatic ?
2. Describe the procedure for tool layout on automatics.
3. What will be the surface speed for cutting the following materials with H.S. Steel on automatics for the operations of turning, drilling and threading ? Brass, mild steel free cutting steel.
4. Briefiy describe the three type of automatics.
5. At what speed does the auxiliary control shaft rovolve ? List the function it performs.
6. How is the speed of cam shaft set up ? How are the various slides traversed by the lead cam and other cams ?
7. Describe the various standard tools and tooling equipment used upon turret type auto-matics. What is balance turning tool ?
8. List the specifications of automatic screw machines. What is the cam blank diameter for lead cam and other cams ?
9. Describe the tool lay out procedure for automatic screw machine.
10. What operation planning considerations must be kept in mind while preparing a process planning sheet for automatics.
11. What steps will you take to make the total spindle revolutions coincide with those provided in the tables ? Why is this step necessary ?
12. Describe a procedure for drawing of cams for turret type automatics ?
13. Define the following with respects to cams :—dwell, lobe, throw, dead centre, blank rise, fall.
14. Describe the procedurs for drawing a rise of fall on a cam.
15. List the special attachment that car be provided on a turret type automatic screw machine alongwith special function of each. Why are they necessary ?

CHAPTER 10

GEAR MANUFACTURING METHODS

Classification Methods

Copying or Forming	Rolling or Generating
(a) Milling	(a) Hobbing
(b) Broaching	(b) Shaping
	(c) Shear Cutting

10.01 MILLING

Milling machines are capable of cutting practically every type of gear by employing an universal indexing mechanism and a form

Fig. 10.01 Cutting Action of End & Disc Types of cutters

cutter. The cutter has the required tooth profile on it. This cutter may be operated on a vertical type or horizontal type of milling

machine. In both cases, the cutter rotates on the spindle and work reciprocates under the cutter (fig. 10.01). Once the cutter finishes a tooth profile the work is indexed for the next position. It is important to keep in mind that two successive teeth should never be milled one after the other because the heat due to metal cutting may distort the teeth. It would be very much safer to finish the teeth on the gear blank after short intervals.

Cutting gears on a milling machine is a very common practice because one cutter with a fixed module number is used for cutting teeth on a blank, irrespective of its diameter, as long as the pitch and module remain same. The practice does not fall in line with the gear theory ; according to 'gear theory', different gears with different number of teeth but same module differ to some extent in tooth profile. If the theory is to be rigidly followed then a set of cutters should be employed. A most common type of set possesses eight cutters but sets with 15 cutters are also available.

Set of 8 cutters :

Cutter	*No.*	*1*	*135 teeth and above*
,,	,,	2	*55 teeth to 134 teeth*
,,	,,	*3*	*35 teeth to 54 teeth*
,,	,,	*4*	*26 teeth to 34 teeth*
,,	,,	*5*	*21 teeth to 25 teeth*
,,	,,	*6*	*17 teeth to 20 teeth*
,,	,,	*7*	*14 teeth to 16 teeth*
,,	,,	8	*12 teeth to 13 teeth*

Following additional cutters are included in the set containing 15 cutters.

Cutter	No.	$1\frac{1}{2}$	80 teeth to 134 teeth
,,	,,	$2\frac{1}{2}$	42 teeth to 54 teeth
,,	,,	$3\frac{1}{2}$	30 teeth to 34 teeth
,,	,,	$4\frac{1}{2}$	23 teeth to 25 teeth
,,	,,	$5\frac{1}{2}$	20 teeth to 19 teeth
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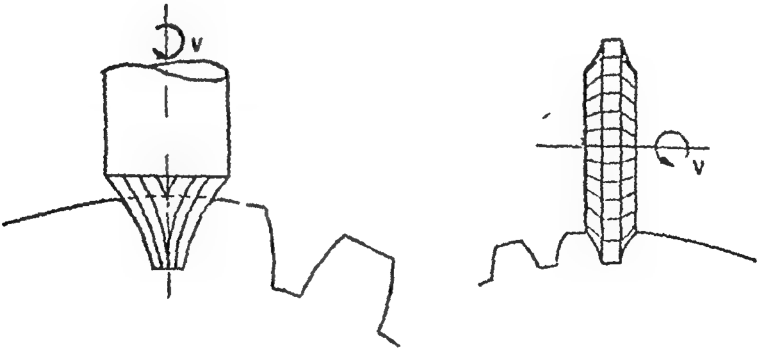

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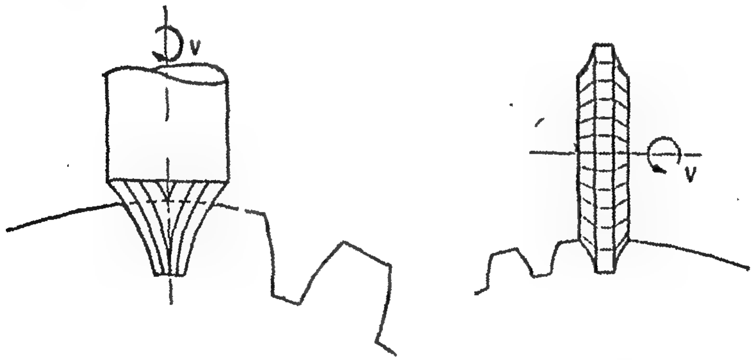

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,,	,,	$4\frac{1}{2}$	23 teeth to 25 teeth
,,	,,	$5\frac{1}{2}$	20 teeth to 19 teeth
,,	,,	$6\frac{1}{2}$	16 teeth to 15 teeth
,,	,,	$7\frac{1}{2}$	13 teeth to 12 teeth

Advantages :

(i) All types of gears *i.e.* spur, helical, worm and in special circumstances bevel gears, can be produced on milling machines.

(ii) The gear cutting can be carried out on a conventional type of milling machine which is normally available in a modern workshop.

(iii) It can be employed both, for roughing and finishing operations.

(iv) The initial cost of the cutter is lower than cutters for hobbing and shaping processes.

Limitations :

(i) Milling is not a production process.

(ii) The pitch accuracy is very much dependent upon the accuracy of the dividing head.

10.02. BROACHING :

Internal gears can be very conveniently cut by a broach tool. This method of cutting works out to be very economical when the rate of production is very high ; due to which it is possible to withstand the first cost of the broach.

The gear cutting action of the broach can be easily understood with reference to fig. (10.02). The figure shows the successive action

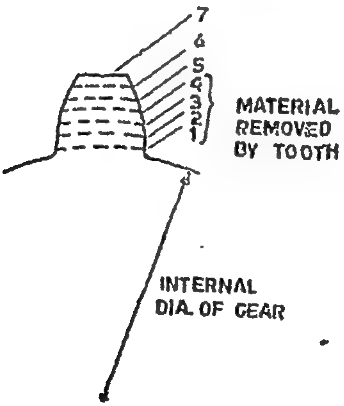


Fig. 10.02 Cutting Internal Gear with a Broach

of the tool over the space in between the two flanks of the consecutive teeth. The broach tool resembles very much to a splinded shaft where each spline is gashed at regular intervals to form the teeth. The complete cutting action is achieved in one stroke of the tool.

Broaching is also capable of producing helical gears on internal surface of a part. For such a job the broach is made to rotate as it advances axially inside the hole.

This process is usually carried out at very slow speeds. The broach seldom operates at speeds above 1 Meter/min.

Advantages :

(i) Most economical when the production of internal gears is very high.

(ii) Thin and small internal gears are easier to make.

(iii) Gears are finished with a high degree of accuracy and finish in one pass of the broach.

Limitations :

(i) Not suitable for external gears.

(ii) Broaching will not cut those gears in which the teeth do not run from one end to the other.

10.03 THE PROCESS OF GEAR GENERATING :

The term 'generating' in gear cutting stands for development of involute curve by straight cutting edges of the cutter, which produces a series of facets on the blank so as to form the involute profile. The cutter and the blank behave as two mating gears in working contact. This generating action is easier to follow with reference to a rack and a pinion. Let the rack be made out of a hard metal and pinion blank from a softer material, say plastics (fig. 10.03). On moving the rack over the plastic

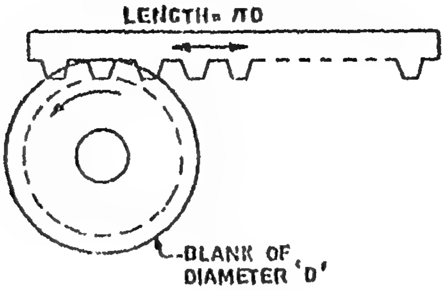


Fig. 10.03 Rack moving on a plastic pinion

blank and permitting the blank to rotate about its own axis the rack will mould the profile of its teeth on the blank. The linear speed of both being kept same. In actual practice since the blank is of metal therefore, moulding is not possible and as such the rack teeth should perform cutting action. This cutting action is obtained by reciprocating the rack cutter about an axis which is perpendicular to the paper or parallel to the axis of the blank. After each cutting stroke the blank is rolled through one pitch while the cutter conducts return stroke. The reciprocating speed of the cutter is quite high. The generating action of the rack is diagramatically represented in (fig. 10.04) which shows the successive position of the gear relative to rack developing involute profile.

In gear cutting practice the rack is seldom used for generating the teeth. The cutter is either a pinion or a worm with relieved cutting edges.

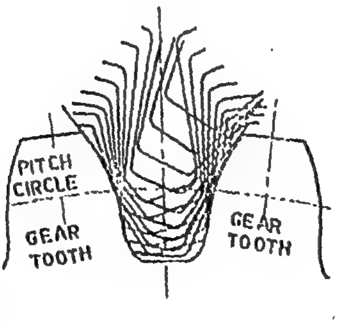


Fig. 10.04 Generating action of a rack

11.031 Hobbing :

In this process the generating action is carried out by means of a typical rotary tool known as hob. The nearest equivalent of this tool is a worm. If the threads of such a worm are gashed lengthwise and then relieved radially for obtaining clearance, the resultant product is the hob (fig. 10.05). The teeth on the hob are with

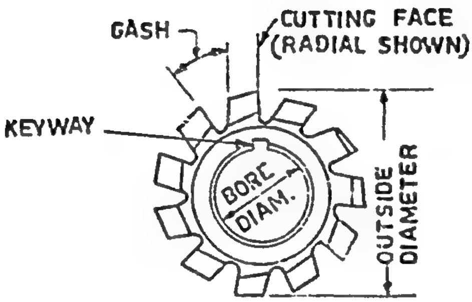


Fig. 10.05 Section of a Hob

straight sides and the tooth form is generated as the hob passes over the job.

The hobs are either single threaded or multi-threaded. A single threaded hob will complete one revolution for the generation of each tooth whereas a double threaded hob will generate two teeth in its one revolution. In this way, the double threaded hob takes less time in finishing the gear blank. The advantage with the use of single threaded hob lies in the fact that it is capable of giving greater accuracy.

The gear cutting with a hob involves three basic motions (fig. 10.06) all of them occuring at a time. Two of these are rotary motions for the hob and blank and the third one is the radial advancement for the hob, both, cutting and indexing taking place continuously.

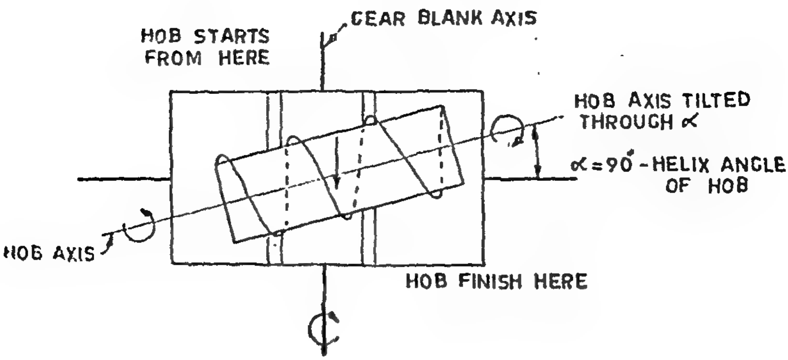


Fig. 10.06 Cutting action of a hob

The hob axis is set at an angle, equal to helix angle of the thread, in reference to the axis of the gear blank. This brings the blank teeth in the plane of the hob's teeth. This plane is termed as *generating plane.* The cutter finishes all the teeth in its one pass-over the work. For cutting helical gears the hob must be set over an additional amount equal to the helix angle of the gear.

To start the cutting, the hob is located so as to clear the blank and then moved inward until the proper setting for tooth depth is obtained. The hob is then fed towards the gear blank in a direction parallel with the axis of rotation of the blank. As the gear blank rotates, the teeth are generated and the feed of the hob across the face of the blank extends the teeth to the desired tooth face width.

Calculations in Hobbing :

In the case of single start hob the hob rotates for number of turns equal to number of teeth to be cut on the blank. During this the blank moves through one complete revolution. Thus, if 32 teeth are to be cut on a blank then the single start hole is made to rotate for 32 revolutions while the blank goes through one revolution. If the hob is double start the hob revolution are 16 for 32 teeth and the cutting is done in a shorter time. This is achieved through a set of change gears. Practically, all the hobbing machines

have certain series of gears provided inside the machine which provide a fixed reduction ratio, therefore while determinining the change gears for cutting a particular number of teeth following relationship is followed :

$$=\frac{\text{Teeth in Driving Gear}}{\text{Teeth in Driven Gear}}$$

$$=\frac{n\times\eta}{\text{number of Teeth on blank}}$$

where n is number of thread on cutter ; for single start, ($n=1$) for double start ($n=2$) etc. and η is constant of the machine drive.

Example : *A single start hob has a 60 mm pitch diameter and right hand helix is to be used for making standard type of spur gear of cast iron. If*

number of teeth=30
module =3 mm
pressure angle =20° at full depth.
face width =30 mm
diameter of hob =50 mm
feed of hob per revolution of blank=2 mm.

Determine rpm of the gear angle between hob axis and work axis, radial depth of cutter and cutting time.

Solution :

(*i*) *rpm* of the gear—

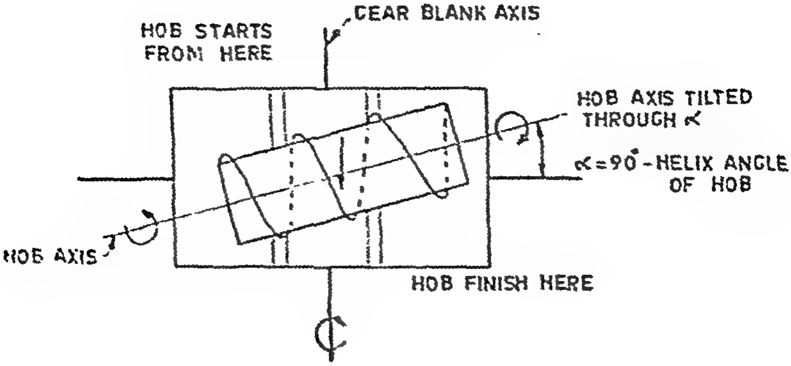
Assuming a cutting speed of 15 m/min. the hob rotates at

$$=\frac{15\times1000}{\pi\times50}$$

$$=60 \ r.p\,m.$$

For 30 teeth to be cut, the hob must rotate by 30 revolution therefore when hob is set for 60 *rpm*, the blank should rotate at 2 *rpm*. **Ans.**

(*ii*) As the teeth are arranged along the axis, its axis is to be tilted with respect to the work axis for cutting straight spur gears. This inclination is equal to helix angle. It is obtained by



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Example : *A single start hob has a 60 mm pitch diameter and right hand helix is to be used for making standard type of spur gear of cast iron. If*

number of teeth$=30$
module $=3$ *mm*
pressure angle $=20^{\circ}$ *at full depth.*
face width $=30$ *mm*
diameter of hob $=50$ *mm*
feed of hob per revolution of blank$=2$ *mm.*

Determine rpm of the gear angle between hob axis and work axis, radial depth of cutter and cutting time.

Solution :

(*i*) *rpm* of the gear—

Assuming a cutting speed of 15 m/min. the hob rotates at

$$=\frac{15\times1000}{\pi\times50}$$
$$=60 \text{ r.p.m.}$$

For 30 teeth to be cut. the hob must rotate by 30 revolutions therefore when hob is set for 60 *rpm*, the blank should rotate 2 *rpm.*

(*ii*) As the teeth are arranged along the axis, its axis should be tilted with respect to the work axis for cutting straight gears. This inclination is equal to helix angle. It is

$$\tan \alpha = \frac{\text{Lead}}{\pi \times \text{hob pitch dia.}}$$

Pitch of the hob $= \pi \times$ module $= 3 \times 3.14$
$= 9.42$ mm

Lead of the hob $= 9.42 \times 1 \quad = 9.42$ mm.

$$\therefore \quad \tan \alpha = \frac{9.42}{\pi \times 50} = 0.06$$

$$\therefore \quad \alpha = 3.4£$$

Hence the required angle $= 90 - 3.4$
$= 86.6°$. **Ans.**

(*iii*) Radial depth of cut

Radial Depth $= 2$ addendum $-$ clearance
$= 2$ modula $+ 0.25$ module
$= 2 \times 3 + 0.25 \times 3$
$= 675$ **Ans.**

(*iv*) Cutting revolution $= \dfrac{30+6}{2} = 18$

$\therefore$ Cutting time $= 18/2 \quad = 9$ min.

Example : *A single threaded hob is to be used for cutting 80 teeth gear. If the hob diameter is 40 mm hob travel is 60 mm, and it is rotating at 100 rpm find the cutting time. Also determine the reduction time is a triple threaded hob is used. The feed may be assumed as 4 mm.*

Solution : The feed is expressed as movement of hob per revolution of gear, therefore during a travel of 40 mm the gear shall make $\frac{40}{4}$) revolutions or 10 revo. while teeth are being milled.

$\therefore$ Hob revolutions $= 10 \times 80$
$= 800$

Actual cutting time $= \dfrac{800}{100}$
$= 8$ min. for single thread

when triple start hob is used, the gear moves through 3 revolution during the time hob executes 80 revolutions.

$\therefore$ no. of hob revolution/gear revolution

$$=\frac{80}{3}$$

$\therefore$ Hob revolution for 10 gear blank revolutions.

$$=\frac{80}{3}\times 10$$

$$\therefore \qquad \text{Cutting time}=\frac{800}{3\times 100}$$

$$=2 \text{ min. } 40 \text{ min.} \quad \textbf{Ans.}$$

External types of gears can be easily cut by hobbing. Not only spur and helical gears are possible to cut by this method but even worm and worm wheels, splines and sprockets can also be conveniently made by hobbing. It is worth noting that a hob of a given pitch can cut involute type spur and helical gears of the same pitch and pressure angle, irrespective of the number of teeth on the blank and the helix angle. Further, the process is quite capable of producing those profiles which are symmetrical (involute) and non-symmetrical (ratchet teeth).

Advantages :

(*i*) Due to absence of indexing operation, reduction in [illegible] approach and continuous cutting action of the hob the production rate is quite high. As a matter of fact, the hobbing is the fastest of all gear generating methods.

(*ii*) Heat generated due to metal cutting is [illegible] tributed over the entire work and [illegible] lity of distortion in the gear is minimum.

(*iii*) High degree of accuracy can be [illegible] ducts over larger period.

(*iv*) Control over tooth spacing, lead and tooth profile is easier.

(*v*) All types of spur and helical gears can be cut on metals non-metals.

(*vi*) A large number of similar gears held on a mandrel can be cut at a time. This reduces the approach time of the hob.

Limitations :

(*i*) Internal gears can not be cut by this method.

(*ii*) Gears which have shoulders and flanges can not be cut by hobbing.

10.032 Gear Shaping :

At the beginning of this century one more method was introduced to industry by E.R. Fellows which, today, is a versatile method of manufacturing gears. Letter of credit is given to Fellows Gear Shaper Co for many facet developments carried out in this field. With this method both internal and external types of gears can be manufactured.

Gear shaping method is based on generating action which is achieved due to the movement of two meshing gears. One of them, *i.e.* pinion, is a cutter while the other is a blank. The cutter makes several facets during its cutting action as the cutter and work rotate. This type of cutting action of the cutter is also known as *moulding generating action.* The cutter is mounted on a vertical ram in a slide reciprocating just as in shaper through a crank arm mechanism. At the same time the cutter also rotates about its vertical axis. The work, however, has the rotary motion (fig. 10.07).

While operating the machine tool, the pinion like cutter is moved aside and the work is loaded on the work arbor. The machine is next started and the cutter is radially fed into the work for the required depth. The feed is given to the cutter while the work is revolving. In the end, the cutter is made to go through

the gear at least once after the desired depth has been attained on

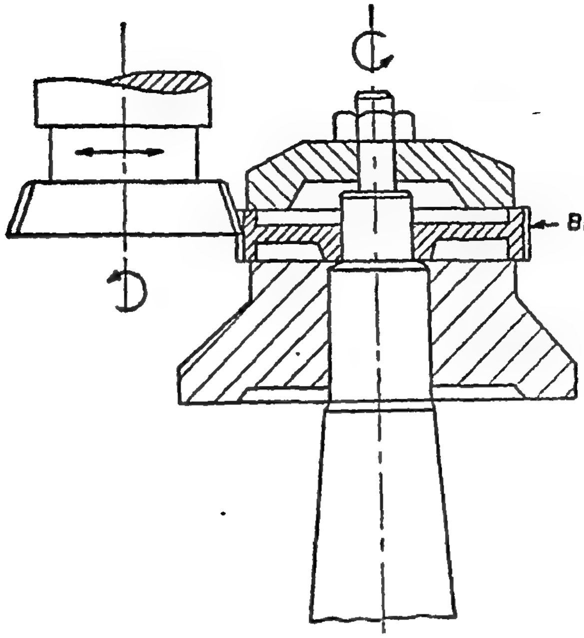


Fig. 10.07 Set up on A Gear Shaper

the blank. To avoid the cutter rubbing over the cut surface, during its return stroke the work is mounted on a relieving mechanism.

The basic nature of the cutter is that of a spur gear each tooth of which has been relieved and shaped for forming proper cutting edge. These cutters are of three types—(*i*) Disc type, (*ii*) Shank type and (*iii*) Hub type (fig. 10·08).

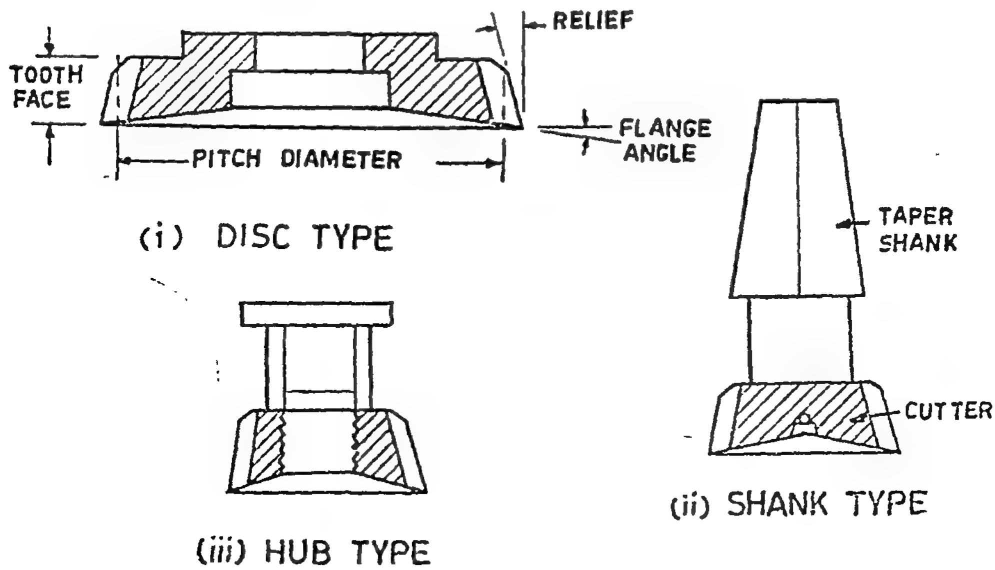


Fig. 10.08 Types of Shaper Cutters

Advantages :

(*i*) One cutter of a right tooth size, pitch and pressure angle can cut gears of various sizes from the smallest pinion to the longest gear which can be easily held on the machine.

(*ii*) Both, internal and external gears can be cut by this process.

(*iii*) Certain non-conventional types of gears *i.e.*, eliptical gears, face gears, cluster gears, gears with shoulders and flanges etc., can only be cut by gear shaping method.

(*iv*) It offers a very high degree of accuracy as the chips of uniform size are cut by the cutter.

Limitations :

(*i*) The length of cut is shorter therefore, gears with wider flanks can not be produced.

(*ii*) The production rate with a gear shaper is lower than hobbing because of differing nature of the motions of the cutter.

(*iii*) For cutting helical gears with different helix angles different helical guides are needed.

(*iv*) Only one gear can be cut at a time.

A considerable interest has been shown by certain automobile industries in U.S.A. to make transmission gears by rolling methods instead of shapers and hob. Ford Motor Co. has claimed much closer tolerances and greater accuracy of the gears made out of rolling in their pilot line. Such a process gives more reliability, longer tool life, less floor space, more uniform production, greater, consistency and higher strength due to grain flow orientation.

Hobbing v/s Milling :

1. In milling the gear teeth can be cut with the use of a milling cutter that has been formed to the shape of the tooth to be cut. As

each tooth is cut, the gear blank is rotated to a new position and then the succeeding cut is made. Thus, it is not suitable for mass production.

This method sometimes produces distortions due to errors n the indexing or due to concentration of heat of cutting which is concentrated at one place.

2. The hobbing method produces gears by means of a hardened cutter called a hob. The production of gears is accomplished having the hob rotate in a fixed relationship to the gear blank. With this action, there is provided a rolling action of the gear in relation to the hob.

3. The important difference between hobbing and milling is that a generating action takes place in the production of hobbed gears, whereas a milled tooth gear has a contour predetermined by the shape of the cutter alone. The true involute profile is produced during hobbing because the process provides true rolling action that further gives maximum smoothness in operation and longest gear. Hobbing also provides uniform angular velocity. Milling, however, does not produce exact involute profile. When considerable variety of gears are to be produced in small quantities and large diameter gears are to be made, milling is preferred over hobbing.

Hobbing v/s Shaping :

1. Due to continuous process of cutting and indexing and non-reciprocating motion of the hob, the hobbing process is faster as well as more accurate. The heat liberated during cuttingis uniformly distributed on the cutter and the work ; therefore, the distortion of gear tooth is never a problem with hobbing. Hobbing machines are much simpler and more rigid in construction because of a few motions involved during cutting. Hobs are easier to manufacture from accuracy point of view.

2. Shaping enjoys wide popularity for one simple reason that it can cut internal types of gears at a very fast rate. Due to shorter

stroke of the cutter, it is possible to cut those gears which have flanges and shoulders in close proximity. Some non-conventional type of gears can only be cut by this process. A large number of identical and accurate teeth are difficult to make on a shaper cutter.

10.04 BEVEL GEAR CUTTING.

Straight bevel gears are cut on a special purpose gear cutting machine tool which employs two 'half teeth' tools. One of it cuts one face of the tooth while the other one cuts the other face of the same tooth. Both of these tools are mounted on a cradle and have reciprocating motions, in opposite directions. At the start, the cradle carrying the tools is rolled in upward position and the blank & cradle are set for required tooth depth. The machine is next started when the tools start reciprocation and the craddle gradually rolls down, moving the blank also along with it. This movement accomplishes the generating action. By the time cradle reaches the extreme downward position the tools complete the tooth profile. The cradle is then rolled back and the tools perform the finishing operation on the tooth profile. When the craddle reaches the starting position, the blank is withdrawn and indexed for next tooth.

Small and straight tooth bevel gears are cut with the help of two disc type cutters. The cutters roll with the blank and produce the teeth.

Bevel gears with curved tooth profile are made on another type generating machine by employing a circular rack type face mill cutter. The cutter axis is parallel to the axis of the roll of the cradle. For cutting, the blank is fed inside towards the cutter to the full depth. The cradle is in its downmost position. Both of them roll together in upward direction. The cutter engages the blank from the small end and moves towards the large end or across the width of the tooth face.

10.05. GEAR FINISHING METHODS

None of the methods for manufacturing of gears on machines can produce gears of very accurate dimensions and shape. Any error in the gear due to these reasons may lead to noisy performance of the gear box, irregular wear of the teeth and uneven load distribution on the teeth. They are sufficient to cause an early failure of the gears. This early failure can be avoided by subjecting the gears to finishing operation, after the gears have been cut on the machines. This finishing operation may specifically be used for

(*i*) rectifying the tooth profile and the pitch.

(*ii*) maintaining the concentricity of the pitch circle and the central hole, and

(*iii*) eliminating the after effects of heat treatment.

10.051 Gear shaving A well hardened helical gear type rotary cutter with serrations on the tooh flank is employed for shaving the flanks of the gear teeth. The cutter (fig. 10.69) removes the raised spots and ridges inthe form of hair like chips.

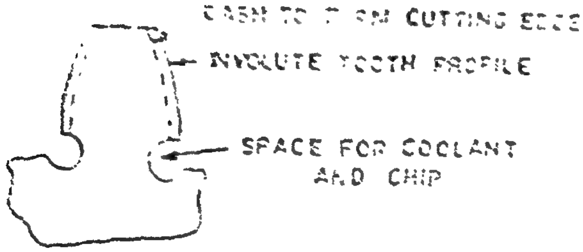


Fig. 10.09 T...

During shavi...
at an angle so ...
the gear rotat...
traverses back a...

This process is usually applied to the unhardened gears and offers a very rapid method for finish. The gears can be corrected within 0.002 mm. It is also possible to shave as many as 9000 to 12000 gears before it becomes necessary to recondition the tool.

Besides using rotary cutters shaving can be performed with rack type cutters.

10.052 Gear Burnishing : Burnishing is a cold working process which is again applicable to unhardened gears. The material from the nondesired regions is plastically moved out by rolling a standard and highly hardened gear over the work gear. Both rotate in perfect alignment. The work gear is rolled under pressure with hardened and accurately finished gears. Though the method provides smooth and accurate tooth profile but due to localised residual stresses, it is never advisable to employ the method on precision gears.

10.053 Gear Grinding : Hardened gears are very difficult to finish by shaving and burnishing methods. Since the heat treatment may cause severe distortion and oxide film formation on the teeth, therefore, there is a necessity for removing considerable stock from the teeth. With the grinding method it is possible to finish the heat treated gears. Though the method is slower and more expensive but it guarantees highest quality gears. Therefore its use is very by limited. The grinding may be carried on generating principle or employing formed grinding wheels.

10.054 Gear Lapping : The object of employing lapping process for finishing gears is to achieve a very high degree of finish. Gears are subjected to by lapping after they have been finished burnishing. Lapping is carried out with the help of two or three cast iron gears which carry abrasives. The C.I. gears are made to run in contact with the gear and a flow of very fine abrasive is

maintained over the contact zone when the lapping takes place in the usual manner. As lapping can remove very small amount of metal this process of finish can only correct small errors max. upto ·05 mm only.

10·055 Gear Honing : Honing is the last operation performed on hardened gears. It also helps in correcting gear errors. Honing removes minor nicks and burrs and gives fine surface finish on the gears contacting surfaces. Surfaces so finished five the gear train the low level of noise emmission required in many applications.

QUIZ

1. On what basis do you classify the gear cutting method ?
2. Describe the principle of gear generating.
3. Sketch a hob and show its various elements on it.
4. How is a gear made by the process of shaping ?
5. Distinguish between hobbing, shaping and milling.
6. What are the various methods of finishing the gears ?
7. How does gear lapping differs from gear honing ?
8. What kinds of gears are made by broaching process ?

CHAPTER 11

MANUFACTURE OF EXTERNAL SCREW THREADS

Producing screw threads with a single point tool on a centre lathe is a widely known method. Usually, a workshop engaged in 'jobbing type work' always prefers this method because, practically all types of threads can be cut on a centre lathe. The method does not prove useful and economical when threads are to be made on a large number of blanks with consistent quality. Other methods that are adopted for the manufacture of screw threads on large scale have been dealt in this chapter.

12.00 METHODS :

Using Die Heads

Thread Milling

Thread Grinding

Thread Rolling

12.01 Using Die Heads : Die heads (fig. 11.01) are self operat

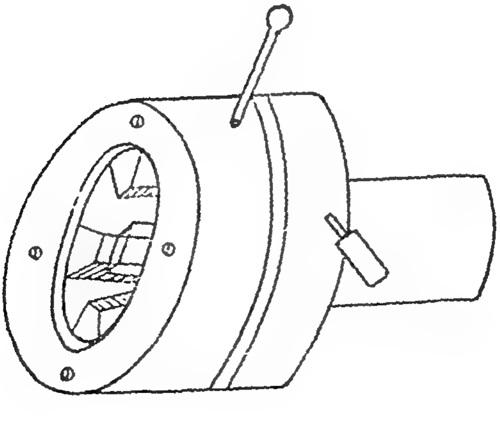


Fig 11.01 Dic head

ing tools which are used for producing external threads on the work. With the use of die heads it is possible to cut threads in comparatively less time and therefore, these are effectively used on turret and capstan types of lathe. Also, these devices have been successfully used on drill presses, automatic screw machines and threading machines.

The cutting elements in a die head are known as chasers, which are of three distinct types—radial tangential and circular Fig. 12.02

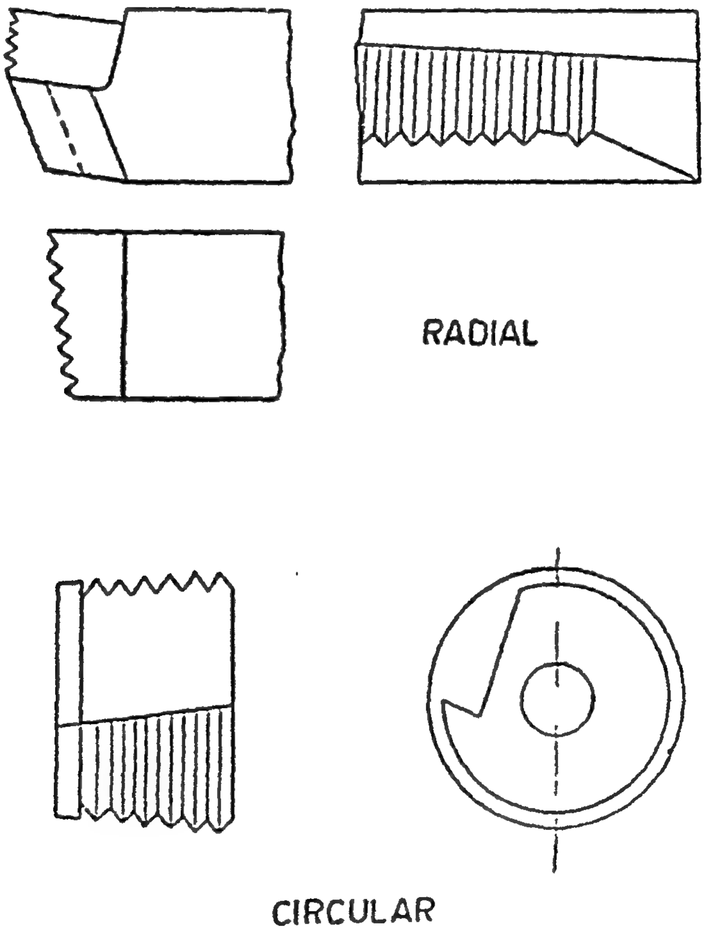
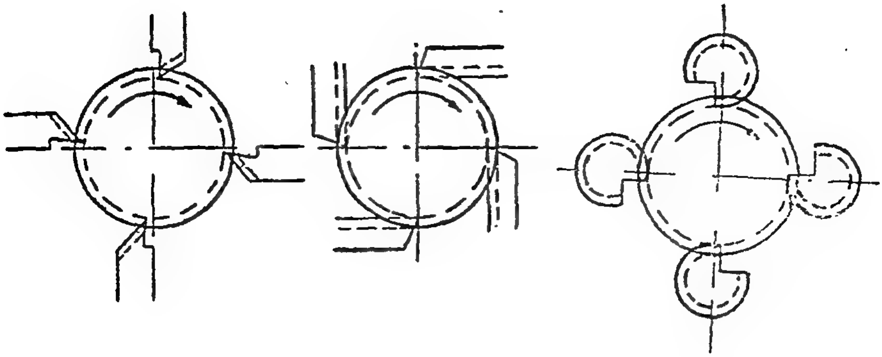


Fig. 11.02 Radial and Circular Chasers

The cutting action of all the three types of chasers are shown in the fig. 11.03. The chasers are nitrided or chrome-plated for better life. Generally, a die head would accommodate four chasers.



(a) (b) (c)

Fig. 11.03 Cutting action of the radial, tangential and circular chasers

While operating the die head, the chasers are set for the diameter of the job with the help of the closing handle. As the die head is made to move over the work, the chasers come into action. When the die head has cut the threads over the required length on the work, a tripping device in the die-head throws back the closing handle into its original position. This return movement of the handle opens the chasers radially outwards. The chasers clear the outer diameter of the threads. Thus, it is possible to withdraw the die-head without stopping or reversing the movement of the spindle.

The self-acting action in the die heads can be achieved in several ways. In one particular type of die head, tripping is achieved by checking the axial advancement of the die head. After a few preliminary trials the axial movement of the head is set for a length of the work. On traversing this length the die head stops but the chasers have a tendency to advance by virtue of the threads already formed and the motion of the spindle. In other words, the chasers are over loaded and hence they make the closing handle to trip and return to original position.

The use of die heads in cutting external threads is advantageous in several ways :

1. Since the stopping and reversing of the spindle is eliminated therefore, it is possible to save considerable

amount of time. In other words, rate of production is increased.

2. The use of die heads facilitates the withdrawl of any damaged chaser or the replacement of one chaser set by the other to suit the thread requirements. Thus, several types of threads can be cut.

3. Thread manufacture with die heads is economical because unskilled workers can be employed on machines.
4. Accuracy of the threads is consistent.

Limitations :

1. Square threads are difficult to cut with die-heads.
2. Screw threads running upto shoulder of the work can not be cut.
3. Screw threads on larger work diameters can not be cut.

12.02. THREAD MILLING :

The method of thread milling is employed when the screw threads finish very near to the shoulder of the work or the work diameter is large. The threads are made in two different ways.

(*a*) In the first case, a thin circular cutter having all the cutting edges in one diametral plane, is used for cutting the threads. The edges of the cutters are formed to suit the thread profile. No lead is provided on the cutter. In order to start the cutting operation, the cutter axis is first swivelled and set at an angle equal to the helix angle of the screw. The work and cutter are then rotated in opposite directions. Besides the rotary motion, the work is also made to advance axially. This method of cutting threads is adopted on longer and heavier type jobs, particularly lead screws of machine tools. Normally full depth of thread is taken in one cut.

(*b*) Another method for milling the screw threads is a high rate production method. A multiple cutter. having width

slightly larger than the length of the threads to be cut is employed for preparing the threads on the work. The work spindle and cutter spindle are parallel to each other. The threads are finished in one revoluttion of the work but the work is made to revolve slightly more than one revolution. This method is adopted when the length of the threads is smaller.

Both the methods can be employed for cutting external and internal threads.

11.03 THREAD GRINDING

Thread grinding method is adopted for preparing threads on the work under two circumstances ; firstly, when a very high degree of precision is required on the threads and secondly, when the hardness of the material is quite high (Rockwell C27 and above) or the material is very soft.

Like milling, thread grinding is also carried on in two ways. The first is adopted for blanks of larger lengths when a thin disc type grinding wheel is used. The wheel is pre-formed according to the thread profile. The wheel while running keeps traversing the length of the thread (fig. 11.04) The wheel runs at a speed ranging from 2000 m.p,m. to 3000 m.p.m. and traverses at a speed of 2 to 5 m.p.m. The threads are finished in one pass of the grinding wheel.

The other method is adopted for threads extending over smaller lengths and finishing at the shoulder. The wheel has more than one pre-formed cutting edges, and the width of the wheel is slightly more than the length over which the threads are to be formed (fig. 11.04)

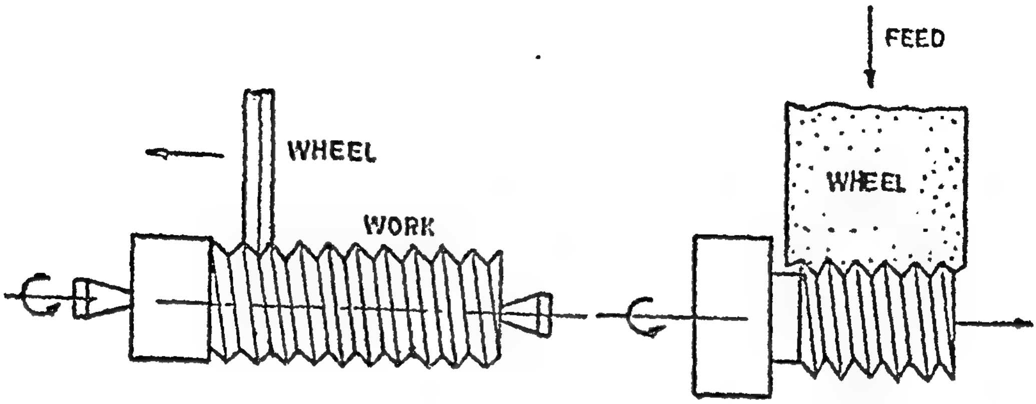


Fig. 11.04 Two methods of thread grinding

To start the cutting action, the wheel is rotated at high cutting speed and then fed to entire depth of the thread. The next step is the movement of the thread through 1.25 revolution and axial advancement of the work by a distance equal to one pitch.

11.04 THREAD ROLLING

Thread rolling is essentialy a cold working process in which the required thread form is impressed on the cylindrical workpiece by rolling it in between hard metal dies. The dies are forced on rotating blank until threads are formed by plastic displacement of metal. The process is carried out on suitable machines by employing fiat, dies or circular threaded rolls. The flat dies have the reciprocating motion and the threads are finished in one stroke. fig.11.05. The

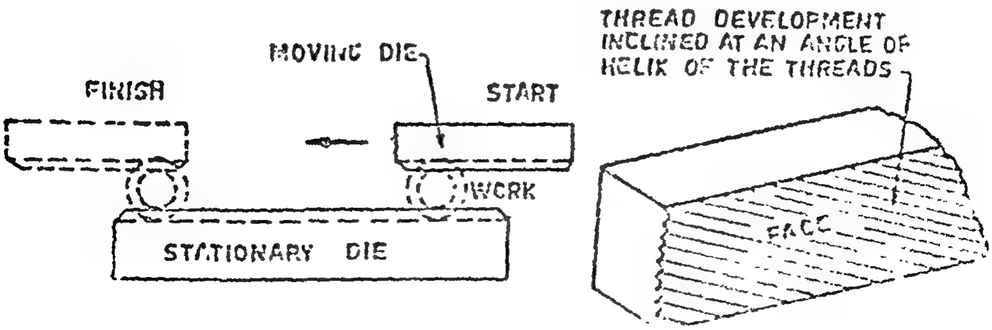


Fig. 11.05 Thread rolling with flat dies

circular rolls have rotary motion and the work is fed in either of the three particular ways as indicated in the fig. 11.06,

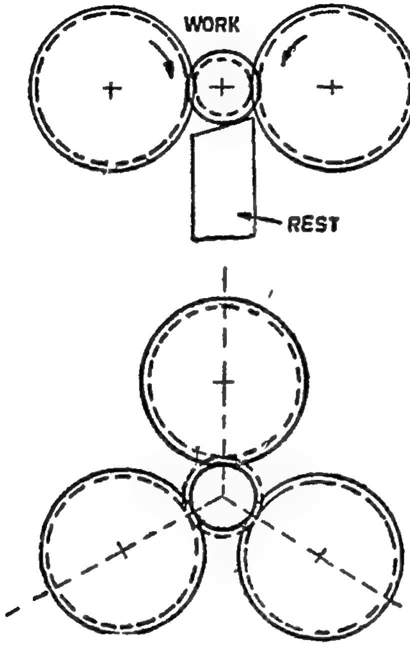


Fig. 11.06 Thread rolling with circular dies

The thread rolling dies and rolls are made of high speed steel or high carbon high chromium oil and air hardening tool steels (1.5% Cr and vanadium and molybdenum).

Use of flat dies is limited to about 25 mm diameter blanks but this method provides a faster rate of production. The rate of production varies from 250 per minute to 40 per minute depending upon the fact whether the blank diameter is smaller or larger.

11.04 CALCULATION OF BLANK SIZE

It is very important that the blanks should contain just the right amount of material to properly form the threads. If the

blank contains more materials, the dies are over loaded, and, if too little material is provided on the blank the thread will not form perfectly.

The calculation of blank diameter is based on the fact that no metal is lost in the process and the thread formation is absolutely due to the plastic deformation of metal. Therefore, the amount of metal displaced from the blank periphery is equal to the metal accumulated above the blank surface, fig. 11 07.

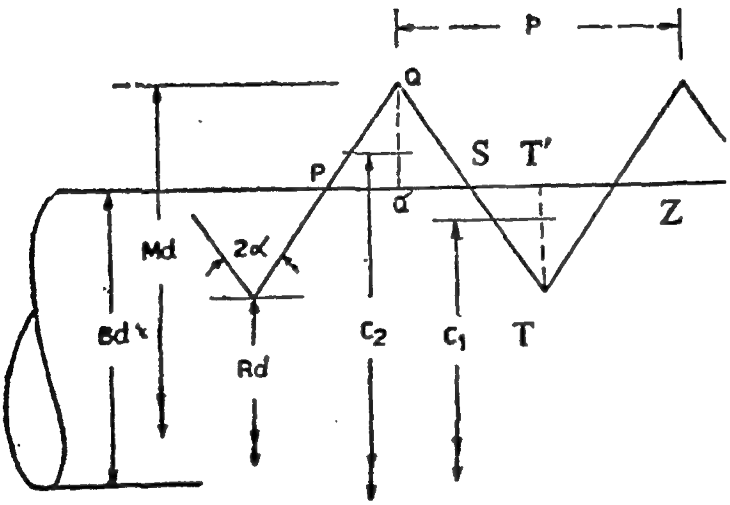


fig. 11.07

Let Bd be rolling diameter of blank

Md be major diameter of the thread

Rd be root diameter of the thread

C_2 be diameter of the centriod of PQS

C_1 be diameter of the centroid of STZ

Volume of the ring represented by the $\triangle PQS$

$$= \text{area of } \triangle PQS \times \text{circumference}$$

$$= \tfrac{1}{4}\, PS\, (Md - Bd) \times \pi\, C_2$$

Similarly, volume of the ring represented by the $\triangle STZ$

$$= \tfrac{1}{4}\, SZ\, (Bd - Rd) \times \pi\, C_1$$

Now $PS=2\ SQ'$ and $SZ=2\ ST'$

$$=2.\frac{(Md-Bd)}{2}\text{Tan }\alpha \qquad =.\frac{(Bd-Rd)}{2}\text{ Tan }\alpha$$

$$=(Md-Bd)\tan\alpha \qquad =(Bd-Rd)\text{ Tan }\alpha$$

$$C_2=Bd+\tfrac{2}{3}\ QQ' \qquad C_1=Bd-\tfrac{2}{3}\ TT'$$

$$=Bd+\tfrac{1}{3}\ (Md-Bd) \qquad =(Bd-\tfrac{1}{3}\ (Bd-Rd)$$

$$=\tfrac{2}{3}\ Bd+\tfrac{1}{3}Bd \qquad =\tfrac{2}{3}Bd+\tfrac{1}{3}\ Rd$$

Then, we can write the following equation

$$PS\ (Md-Bd).\ \pi\ C_2=SZ\ (Bd-Rd)\ \pi\ C_2$$

$$\text{or } (Md-Bd)\text{ Tan }\alpha\ (Md-Bd)\ .\ \tfrac{1}{3}\ .\ (2Bd+Md)=(Bd-Rd)\tan\alpha\ (Bd-Rd)\ \tfrac{1}{3}\ (2Bd+Rd)$$

$$\text{or } (Md-Bd)^2\ (2Bd+Md)=(Bd-Rd)^2\ (2Bd+Rd)$$

$$\text{or } Md^3-Rd^3-3MdBd^2+3Bd^2\ Rd=0.$$

Example :

Calculate the blank diameter for cold rolling 12 mm diameter 60°V threads with 1 mm pitch on a mild steel blank.

$$\text{Depth of thread} =\tfrac{1}{2}\text{ Cot }30^\circ$$

$$=\tfrac{1}{2}\ .1.732$$

$$=0.866\text{ mm}$$

Major diameter $=12$ mm, Root diameter $=12-1.732$
$=10.268$ mm

On substituting the values in the above equation.

$$12^3-(10.268)^3-3\ (12)\ Bd^2+3(10.268)\ Bd^2=0$$

$$1728-1081-36Bd^2+30.804\ Bd^2=0$$

$$\text{or}\quad 5.196\ Bd^2=647$$

$$Bd=11.4\text{ mm.}$$

Merits :

1. Threads are accurate and uniform.
2. Excellent surface finish is obtained because of the burnishing action during rolling. Surface finishe of 1 micron and below can be produced on the threads.
3. Inspection is considerably reduced.
4. Rolled threads are much stronger than machined threads owing to the improvement in tensile and shear strengths due to cold working. The formation of the grain flow in the threads increase the resistance to stripping of threads.
5. Thread rolling is the fastest known method for manufacturing the threads.
6. Large material saving is often achieved compared with machining as no swarf is produced. This saving may range from 15% to 30%. Absence of swarf further reduces the cost of its removal from the machines.
7. Long die life is obtained and the dies do not require resharpening. Thus, tool maintenance costs are low.
8. Thread rolling method can also be employed for knurling, burnishing, cutting splincs and serrations and helical grooves.

Limitations :

1. By and large, thread rolling process is confined to the production of external threads.
2. Sometimes, rolling results into lengthening of the work and therefore, provision for this must be made, if the length is critical.
3. Square threads are difficult to produce.
4. Coarse-pitch-threads with steey flank angles are difficult to roll with satisfactory finish.

5. Die life decreases with increasing work hardness. In general, Rockwell C 40 is the economic limit for thread rolliing.

QUIZ

1. What are various methods employed for manufacturing external threads ?
2. How does a tripping device functions in a self acting die head ?
3. State a few limitations of die hear.
4. Under what circumstances thread milling and thread grinding methods are adopted ?
5. Distinguish between flat die and circular die rolling methods for producing screw threads.
6. How do you obtain the blank diameter ?
7. State five principal advantages of thread rolling method.

CHAPTER 12

FINISHING AND SUPERFINISHING

The grinding of a metal is used to a certain extent as a surface finishing operation. Basically, it remains as a metal removal operation and it is still used as one of the shaping methods. With this operation a surface finish in the range of 1.25 μ to 0.75 μ can be achieved. These values refer to arithmatic mean values. For a still better finish a few other methods and operations have been developed which can provide a finish upto 0.01 μ. These operations are lapping, honing, superfinishing, burnishing and buffing.

12.01 LAPPING :

Lapping is an abrading process. It is carried out either by introducing abrasive compounds between the moving workpiece and a lap or by employing a solid bonded abrasive. A lap is a solid rectangular or circular block of cast iron or bronze. The lap is held over the workpiece under a controlled pressure and it forces the abrasives to remove the metal in the same fashion as in grinding. By devising suitable equipment, lapping can be performed on both, flat and cylindrical surfaces. Again in cylindrical surfaces both, the shafts and holes can be suitably lapped. Gauge blocks are lapped to $\pm$ 0.02 mm per meter length and opposite faces are also made parallel within these dimensions.

Lapping pressure, being light, does not induce heat or strain in the finished part as in grinding, yet produces a more accurate surface.

Lapping is performed primarily to increase accuracy, improve surface finish and match the mating surfaces.

Abrasives used in lapping are either of the natural or the artificial type. Very hard surfaces such as carbides require diamond or silicon carbide grits ; softer materials including steel can be lapped with aluminium oxide, emery or corundum. Lapping compounds are available in the market mixed in an oil which serves as carrier for the grits. Lapping can be classified in several ways such as hand lapping and machine lapping, hole lapping and shaft lapping.

(*i*) **Hand Lapping** : In hand lapping the compound in an oil base is spread over the surface of lap. A lap is made of cast iron, bronze or copper. The material of the lap being soft, some of the compounds get stuck into the surface of the lap when the work piece is rubbed over the lap. Such embedded work pieces behave like abrading particles of a grinding wheel. Some times shallow grooves are cut into theplate to provide space for any excess lapping compound.

(*ii*) **Machine Lapping** : In machine lapping, the lapping plate becomes a rotating table. The parts to be lapped are confined into cages that impart a rotary and gyratory motion at the same time, covering the entire surface of the lapping table. Parallelism is maintained by having a stationary lapping plate on the top of the work pieces.

Some times it is desirable to have two surfaces matching within extremely close tolerances as in valves and valve seats. The lapping compound is placed between the two parts after which one of the members is rotated. Gear and threads are also corrected in this manner. The above arrangements of lapping are for flat surfaces.

(*iii*) **Cylindrical Lapping of Shaft type Work-pieces** : External surfaces of revolution can be lapped either on ordi-

nary lathes with hand laps (fig. 12·01) or on special lapping machines.

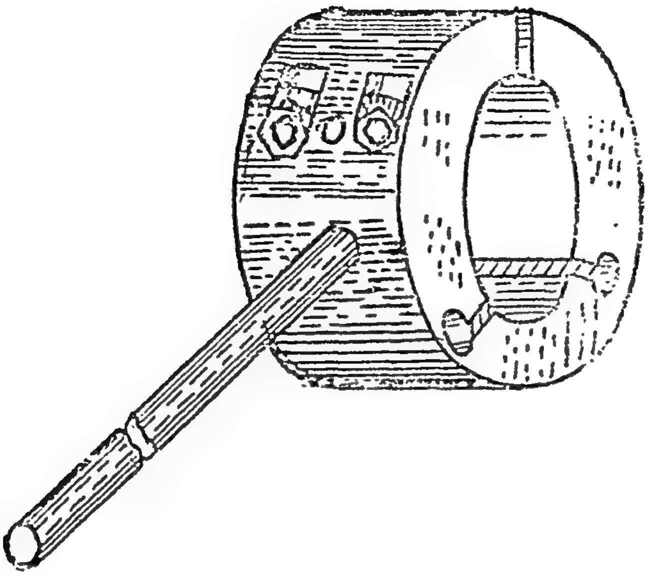


Fig. 12.01 Hand lap for use on shaft type work pieces

Such a special lapping machine has two cast iron discs (laps) mounted on vertical spindles. The lower lap is rigidly secured to its spindle while the upper lap is swivel-mounted so as to align with the lower lap surfaces. The upper and lower spindles rotate at different speeds. A movable cage is arranged between the laps.

It has openings to accommodate the work to be lapped. An eccentric mechanism imparts a rotary motion to the cage about a point arranged eccentrically in reference to the centre of the lower lap. Consequently, the work pieces in the opening of the cage not only roll between the laps but have an axial movement also. Due to this feature and to the different peripheral speeds of the laps, a relative sliding motion is obtained between the work and the laps, and work is removed from the work surface.

(*iv*) **Lapping Holes** : Laps for holes consists of sectors ranging from 2 to 6 in number mounted on the arbour and expanded by springs or cones (fig. 12.02).

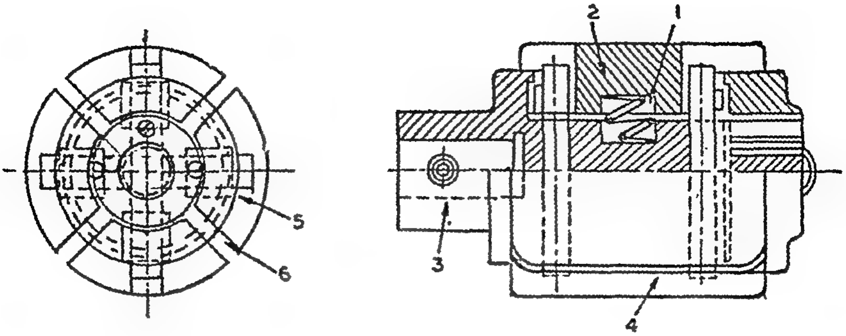


Fig. 12.02 A lap for holes

The lap is inserted into the hole where is it is rotated and reciprocated. Surfaces of laps are charged with lapping compounds. Holes are rarely lapped in production shops due to slow production however lapping is used for finishing holes in tool room in gauges.

(*v*) **Bonded Abrasive Lapping** : Lapping compounds tend to leave a dark, dull surface that is hard to remove. Solid bonded abrasives are used on machines toremove the lapping compound and improve the finish.

12.02. HONING

If lapping action resembled to that of grinding, the honing operation resembles to turning. The only point of difference is a number of cutting edges operating on the work surface in the case of honing. The honing operation is more productive than lapping for finishing holes. Instead of a lap and lapping compound, it uses fine abrasive grits held within the binding material of the honing stone. The development of honing stone is now so advanced that it is possible to hone all metal including non-ferrous metals, aluminium alloys etc.

Honing is carried out at a low speeds. The honing stone has a tendency to build up material removed during the process which tends to increase the local heat. The lubricant and coolant used

during the lubrication does not flush out the microchips and therefore cooling and chip removal is not very efficient. Thus, higher speeds will cause excessive heat generation. Usually, the honing operation is done at 10—30 m/min. This cutting velocity is a resultant of the stroke velocity and the peripheral velocity of the stone. This process maintains the surface finish between 0.2 μ to 0.05 μ and the tolerances within ±·002 mm. The ten most common errors in bore production like rainbow, taper, out of round, waviness, diameter bell mouth and barrel, boring tool masks, misalignment and reamer chatter are removed by honing. Out of roundness and taper may be eliminated.

(*i*) **Honing Process :** The work piece must be rigidly clamped on to the work-table. Care must be taken to keep the bore exactly parallel to the axis of the honing spindle. The bore must be centred on the spindle not with the honing awl, which is coupled via a ball joint but insteaddirectly with the spindle itself, to an accuracy of 0.1—0.2 mm. It is necessary to set up the job exactly, inspite of the flexible joint, if precise bores are required. The form of the bore can be damaged with the slightest sideways pressing of the honing awl.

The stroke and working length must finally be adjusted, which the hone must follow in order to obtain a good cylindrical bore.

A good practical rule is for the honing stone to over run the bore by $\frac{1}{3}$ of its length above and below. Care should however, be taken that the stone is not longer than 60% of the depth of the hone stone that are too long usually give increased diameter at the start and end of the bore, as the grinding surface of the stone decreases when it over runs at the end of the bore due to a part of it leaving contact. Because of the constant advance pressure on the awl, the specific pressure increases correspondingly at the ends and this leads to a larger rate of metal removal.

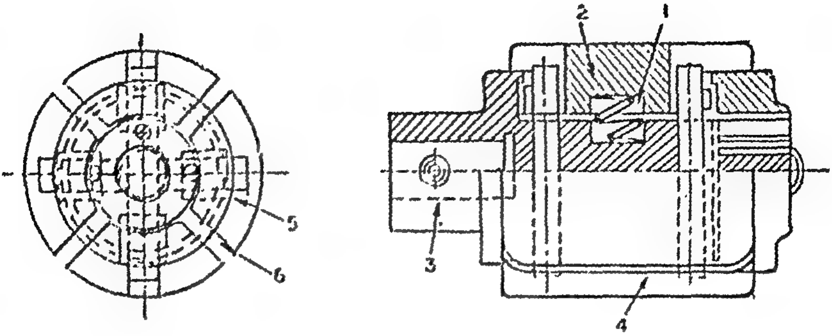


Fig. 12.02 A lap for holes

The lap is inserted into the hole where is it is rotated and reciprocated. Surfaces of laps are charged with lapping compounds. Holes are rarely lapped in production shops due to slow production however lapping is used for finishing holes in tool room in gauges.

(*v*) **Bonded Abrasive Lapping** : Lapping compounds tend to leave a dark, dull surface that is hard to remove. Solid bonded abrasives are used on machines toremove the lapping compound and improve the finish.

12.02. HONING

If lapping action resembled to that of grinding, the honing operation resembles to turning. The only point of difference is a number of cutting edges operating on the work surface in the case of honing. The honing operation is more productive than lapping for finishing holes. Instead of a lap and lapping compound, it uses fine abrasive grits held within the binding material of the honing stone. The development of honing stone is now so advanced that it is possible to hone all metal including non-ferrous metals, aluminium alloys etc.

Honing is carried out at a low speeds. The honing stone has a tendency to build up material removed during the process which tends to increase the local heat. The lubricant and coolant used

Internal honing is carried with the help of abrasive sticks which are mounted on the expanding head or hone in the holders (fig 12.03)

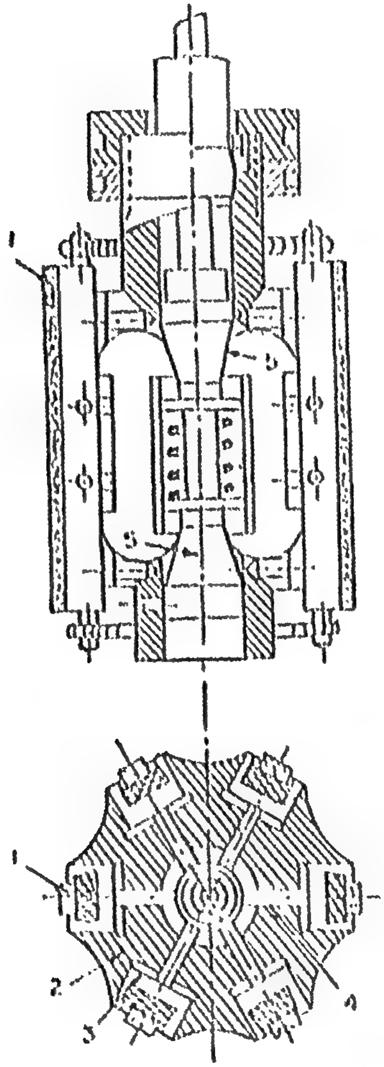


Fig. 12.03 Internal honing

By spring or wedge action the stones can be fed over a predetermined distance during the honing operation. The desired honing pressure is also set. The hone is connected to the machine spindle through universal joints which allow it to align itself with the hole. The hone

both reciprocates and rotates for proper action. The method is mostly used for finishing automobile cylinders.

In some instances the hone is of the rigid type and the work is held in a floating fixture.

Honing of external surfaces can be successfully accomplished by mounting 4 sticks held in holders on a contracting yoke. The work piece is rotated while the sticks envelope the work piece. Hand pressure only is applied on the sticks.

The spindle speed in honing is larger than number of strokes The honing allowance on steel parts is about 05 mm. A hone 20 mm and 65mm long can remove 00375 mm per minute in hardend tool steel and 0.10 mm minute in annealed steel SAE 1020. Abrasive sticks for hoding are made of grit (aluminium oxide, silicon carbide or diamond) bond (vitrified clay or resinoid) and air volds. The way in wich these factors are balanced determines how the abrasive will act on any particular part. Abrasive sticks with a grain size of 30 to 500 are used for honing.

(*ii*) **Honing Fixture and Honing Machines :** The reciprocating and rotatory motion of a hone can be produced in any machine like drill press or electric drill, however, the results obtained with this type of equipment will not be so consistant or so economical as those done on a honing machine, which may be a multiple spindle vertical hydraulic machine equipped with automatic bore gauging size control and hydraulic honing tools. Such machines have a indexing table on which several workpieces can be mounted on specially designed honing fixtures. Indexing table makes the loading and unloading of pieces possible while the machine is still working on some piece.

(*iii*) **Advantages of honing :**

1. Several holes may be honed simultaneously on multiple spindle machines.
2. Holes of any diameter or length may be h

3. A high degree of accuracy and surface finish can be obtained.

4. Relatively high productivity as compared to lapping.

(*iv*) **Disadvantages :**

Tough non-ferrous metals cause glazing or clogging of the voids of the abrasive sticks and thus they are difficult to hone.

A new development in the field of honing is diamond honing wheel was developed essentially for cast iron. It is now extensively used on soft and hard steels, cemented carbides, aluminium and brass. Parts like cylinder blocks and liners, refrigerator compressors, gears and connecting rods are processed by diamond honing.

12.03 SUPER FINISHING

Previously ground external surfaces of steel, cast iron and non-ferrous alloys are finished by abrasive sticks as in honing to a very fine accuracy by the method called super-finishing. The abrasive stone or the stick is mounted on the end of a spring loaded quill. The assembly has an oscillating mechanism by which the stone can move back and forth parallel to work piece axis a maximum distance of 5 mm at 425 cycles/min. The assembly can be mounted on the cross slide of a lathe or on a machine especially designed for the purpose. The traversing motion to the stick is also provided if the job is larger than length of sticks. The stone is formed to the radius of the work by putting emery cloth over the workpiece face. As the stone contacts the emery cloth, it is soon worn to the radius. After the stone is dressed to the radius of the job, it is brought in contact with the work at about $\frac{2}{3}$ or kg/cm^2 pressure. The part is rotated at a speed equal to 20 mpm. The oscillator. motion is started and coolant (a mixture of kerosine and oil) is used to flood the area. If the job is long the traverse motion is also given along with oscillatory motion to the abrasive sticks.

It is employed to practically, get rid of the peaks and valley within a submicroscopic range.

Flat surfaces can also be super-finished according to this principle in which there should be two spindles (fig. 12.04). The lower spindle holds the work and rotates it. The upper spindle is a spring loaded quill on which a stone is mounted. The upper spindle only rotates at off centre position. It need not oscillate however it can traverse if the work dimensions demand it. Supper finishing process utilises an abrasive stock of very fine grain size (400 to 600). Longitudinal feed or traverse of the stick is 0.1 to 0.15 mm per revolution of work finished by this method.

Super finishing is not a process designed to remove material or correct part geometry as in honing. It reduces the crests of a surface. This reduction in height helps in the maintanance of a proper film of lubrication between the hole and shaft. The crests always create the danger of film being punctured and quicken the wearing

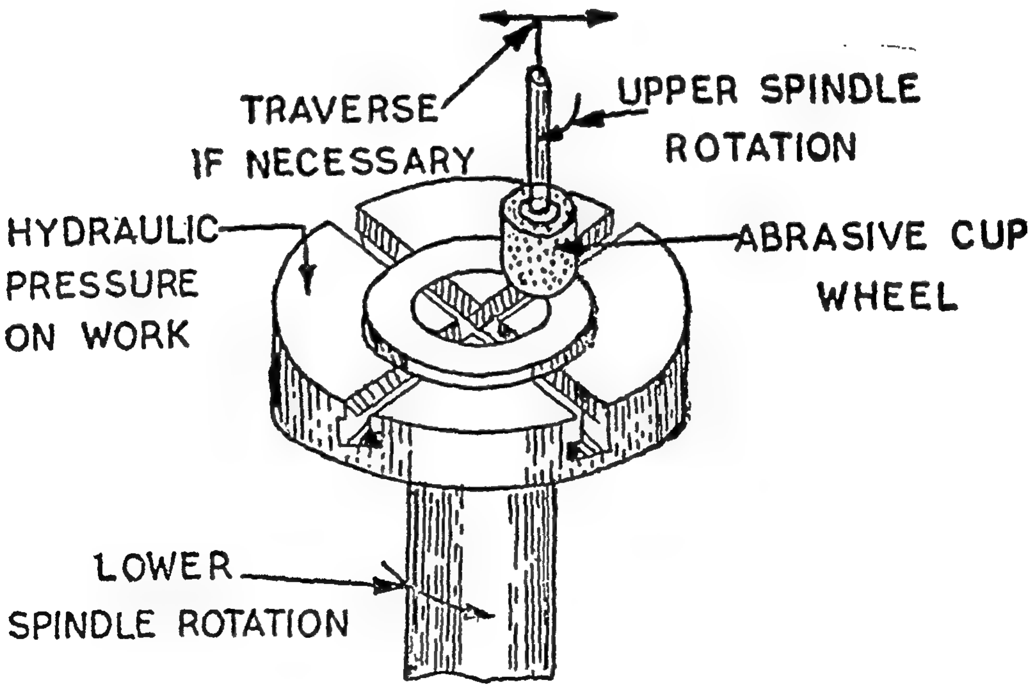


Fig. 12.04 Super finishing of flat surface

of the mating parts. The amount of material removed from the part may range from 002-·010 mm to on the diameter. The surface

finish produced ranges from less than 1 to 0.80 μ with average around 0,5μ to ·010 mm. For a surface to be smoother than 0.5 μ the super finishing time increases Normal super finishing operation takes about 0.2 to 0.5 minutes. As in lapping and honing the high quality of surface obtained in super-finishing is due to :—

1. Low specific pressure of the abrasive stone on the work surface.
2. Low cutting speeds.
3. Oscillation of the abrasive sticks.
4. Low temperatures generated.
5. Combination of oscillation and traverse movement bringing new cutting grains in contact with the work piece and at the same time removing chipped material away from scene by excessive coolant.

Automobile parts that are super-finished can be listed as tappet head, crank shaft, brake drum, pressure plate, tappet body, cam shaft, main bearing etc.

12.04 BURNISHING

The burnishing of metals is a method for producing smooth surfaces by plastically moving away the raised micro-irregularities on the surface and pressing it into the micro-cavities. This produces a new surface with a high degree of finish.

The process is carried out with a highly polished ball or roller type tool which is traversed under pressure over a rotating workpiece. When the tool starts the operation it produces as profile similar to ball curvature. With the feed given to the tool after one revolution, the tool plastically deforms more metal. A small amount of the previous metal springs back. Both, the deformation and springing back of metal continue with more and more feed given to the tool. In the end of the tool traverse, it results into a smooth finished surface.

The quality of the surface produced depends upon the ball diameter, force, method of force application and the hardness of the material. The improvement of the surface may range between 4 to 10 μ. The earlier condition of the surface also plays an important role on the degree of improvement achieved by the method.

12.05 POLISHING

Polishing is the smoothening of a surface by cutting action of abrasive particles adhered to the surfaces of resilient wheels of wood, felt, leather, canvas or fabric or attached to belts operating on resilient wheels. Polishing of metal is done to impart a high grade finish to the surface for the sake of appearance. Polishing is not used to control size. Artificial abrasives aluminium oxide and silicon carbide are commonly employed under various trade names. Natural abrasives can also be used. They are flint, emery and garnet. The mesh size in both cases ranges from 12 to 400. For best results in polishing the wheels or belts are run at 3000 surface meters per minute.

Many kinds of machines have been built to bring the coated abrasive in contact with the workpiece. They may be broadly classified in two groups. The endless belts machines and the coated abrasive wheels. Belt machines are of various designs to suit the job. Coated abrasive wheels are made up of hundreds of small abrasive strips mounted on a hub. It has the advantage of conforming to a wide variety of contours without having to be made to any special form. The abrasives coated form a resilient surface, cushioned by their own flexibility.

12.06 BUFFING

Buffing is the smoothening and brightening of a surface by the rubbing action of fine abrasives in a lubricating binder, applied intermittently to a moving wheel of wood, cotton or fabric or felt or a cloth or felt belt. The lubricating binder containing the abrasives may be applied either from a solid bar or by spraying [illegible]

liquid. Buffing wheels are designated by the way in which they are sewed :—concentric, radial, radial arc, parallel, and square. Some loose wheels have only a row of stitching around the hole. Buffing is used give a much higher, lustrous, reflective finish than can be obtained by polishing. For a mirror like finish, the surface must be free of defects and deep scratches. Here also the abrasive mixed in the lubricating binder is aluminium oxide. A colouring operation that brings out the best colour and lustre of the metal is done by using a white compound of alumina type abrasive.

Buffing wheels are mounted generally on buffing lathes or simply buffing machines which are run by belt drives from motors at the back. Wheels are mounted on both sides on such machines. Buffing speeds are little higher than polishing *i.e.* 4000 m/min, however surface speeds of 2500 m/min. should never be exceeded for colour buffing.

QUIZ

1. List some methods of finishing flat and cylindrical metal surfaces.
2. What are the charateristic features of lapping and honing ?
3. How is the cutting velocity of a hone defined ?
4. Why honing is carried out at low cutting velocity ?
5. What is the principle of super finishing operation ?
6. What kind of operation is burnishing ?
7. Distinguish between polishing and buffing.
8. Give at least one typical example of each of the surface finishing operation.

CHAPTER 13

BROACHING

Broaching operation employs a special kind of multi-tooth tool, called broach, which finishes the complete metal removing operation in one stroke. The metal can be removed from flat as well as non-flat surfaces by the broach. During its cutting stroke the tool performs both roughing and finishing operations on the workpiece. This makes the broaching a very rapid method of metal machining and also, the method has proved itself very economical in large scale manufacture of certain components in automobile industry. Although originally, it was developed for cutting keyways ; broaching, today, is employed on a large variety of components.

BROACH

The broach is a special purpose tool which has a series of regularly spaced teeth. Each tooth of the tool has different height and the height is in progressively increasing order. Due to it each tooth participates in the cutting action. Broach is in the form of a bar of different cross section. The most common type is a circular broach (fig. 13.01). The essential elements are all indicated on the sketch.

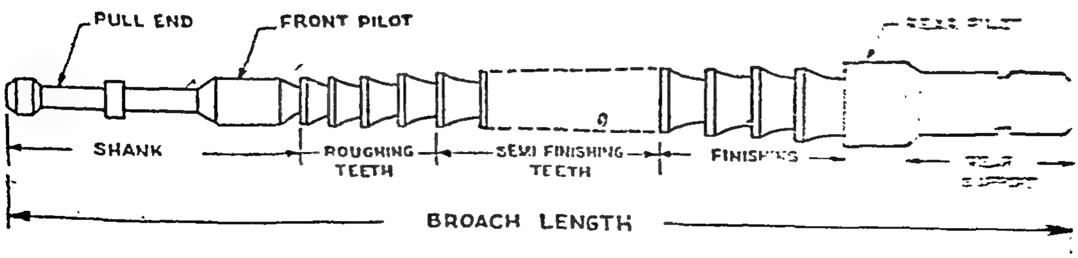


Fig. 13.01

Cutting Action of Broach :

The cutting action of the broach can be divided into three parts—roughing, semi-finishing and finishing. All the three operations are done by one tool in its cutting stroke. The roughing teeth take maximum depth of cut and the finishing teeth take the minimum. The last four or five teeth do not participate in the cutting action. These are burnishing teeth and they only spread out the micro-crests and thus, produce a smooth and even surface.

The modern trend is to provide chip breakers on the roughing teeth. The teeth are nicked by a small amount which provides discontinuous chip and reduces the stresses on the cutting edges.

BROACHING OPERATIONS

1, Internal Broaching.

2. External Broaching,

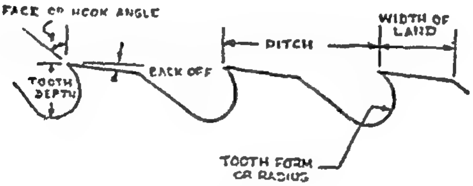


Fig. 13.2

Internal broaching operation is adopted for producing internal surfaces such as holes keyways and teeth of internal gear. A few of the examples are given in (fig. 13·02). For carrying out internal broaching, it is very essential that there is no obstruction on the other side of the hole, so that the broach can execute its cutting stroke completely. The internal broaching is always started with a drilled or cored hole in the body whose diameter is greater than the size of the pilot of the broach. The pilot is held in the puller, if the machine is 'pull type'. The machine imparts straight line motion and cutting power to the broach. On completion of the job broach retraces its path.

External broaching is employed for machinig a flat surface. The broach is in the form of small length tool mounted on a slider. It is kept in position by the slider having a guided motion all over the traversing length. The workpiece is held in a fixture. During the return stroke of the broach, the workpiece is removed from the position so as to avoid the rubbing of the broach on the work surface. Some of the notable examples of surface breoching, as it is also known, are the surface machining of the automobile cylinder heads and gear parts.

BROACHING MACHINES

Broaching machines are available now in many designs and shapes. These have been therefore, classified in different ways by different manufacturers. But looking at the functional aspects of the machines these can be classified into two main groups i.e., horizontal broaching machines and vertical broaching machine. Each group can have more subclasses based upon the pulling actions on the tool, kind of drives, number of rams and the type of controlling devices, used in the machine.

The selection of the machine is based mainly on the nature of jobs. For example, if a heavy metal removal rate is desired then a horizontal machine is preferred over a vertical machine. When a high rate of production is to be achieved a semiautomatic or automatic machine is selected. Usually, the broaching machines are hydraulically operated .

Power Consumption

The cutting velocity relationship for a broach is expressed in the form given below :

$$V=\frac{C}{T^{x}s^{y}}\,k \text{ m/min}$$

Where c=constant concerning to working conditions

k=another constant related to broach material

T=tool life in minutes

s=depth of cut per tooth, mm

x, y=exponents each having values 0·62

Usually C=12, and T=100 min.

$$\text{Power for broaching} = \frac{PV}{60 \times 120} \; kw$$

Where P is cutting force or is following pull given by

$$P = C_1{}^{0\cdot85} \, dz \text{ kg}$$

in which C_1=constant related to broach material

s=depth of cut/tooth mm

d=broach diameter in mm

z=no. teeth engaged at a time

$$\text{Broaching Time } T_o = \frac{h\,L\,A}{1000\,v\,s\,z}$$

h=machine allowance on each side

L=length of broached surface

A=ratio between the return stroke speed to the working stroke speed.

BROACH DESIGN

The design of broach is much more complicated than the design of any other multi-point cutting tool. An error of slightest magnitude is sufficient to damage the broach incurring a heavy loss as the tool becomes unserviceable. This is the reason why the manufacture of the broach is only taken up the specialists in this field and they could be just counted on fingures. In the following paragraphs only

those design aspects have been dealt with which could be easily understood. The purpose is not to give any expert practical approach towards the design of a broach but to put forth the salient features of the design procedure before the students of production engineering.

Step 1 : The design of a broach is started with the study of the geometry of the workpiece. This helps in deciding the form of the broach.

Step 2 : The quantity of the products to be manufactured decides the material of the broach. For quantities less that 3000 workpiece high carbon steel may be preferred. High speed steel is the most widely used broach material which can produce upto 10000 parts without service or replacement. The production rate and capacity of the broach can be increased by using carbide inserted tooth broach.

Step 3 : The designer should know whether he is required to design a broach for pull type action or fresh type action. With this information he works out the proper size of the pilots and shanks.

Step 4 : A broach should possess sufficient strength which fixes its minimum cross section. The minimum section may occur at the root of the first tooth or the shank at the pull end. The cross section (A) can be determined by the following relation

$$A=\frac{\text{maximum pull}\times\text{factor of safety}}{\text{ultimate shear srsength}}$$

From this, the area at the maximum root section can be computed. In case the pull end has a provision for cotter, it should be checked if the minimum cross section do not exist at the slot. This could be had as below

$$A=\frac{\pi}{4}\,(\text{diameter of pull end})^2-\text{width of slot}\times\text{diameter of the pull end}$$

For a push type broach the section is worked out by treating the broach as column because the length is for greater than the diameter. A suitable factor of safety should be incorporated which could be best judged by experience in the trade.

Step 5 : The next step is the decision on the pitch of the tooth (P). This is determined with the help of an emperical formula

$$P = 0{\cdot}35\sqrt{L}$$

where L is the length of cut, both P and L are in the same units. However in this direction it is always advisable to provide at least 3 teeth over the length of contact so as to avoid any drifting of the tool. This fixes a minimum value of P as 0·33 mm. The above relation just helps in arriving at a number. It is always upto the designer to vary the value depending upon the size of the work surface and work material. He is more guided by the two factors. Therefore, it is really hard to set a rule. Anything said on this is simply a nearest approximation. One thing is sure that the pitch remains same over the entire length of the broach. Differential pitching is also suggested to bring down vibrations while machining hard materials.

Step 6 : Another important consideration for a designer is to decide the depth of tooth and the root radius. Both are very important for the correct formation of the chips in the space The correct formation is a complete curl and not crumbling of chips in the space. Broken chips get packed in the gullet and obstructs the flow of the fresh chips. This leads to considerable increase of stresses on the cutting tooth. The desirable condition could be had by increasing the depth of cut but this would reduce the cross section and weaken the broach. A certain broach making industries use depth of cut (*d*) in the range of 0·30 P to 0·4 P and gullet radius as $\frac{d}{2}$. The lower value of *d*

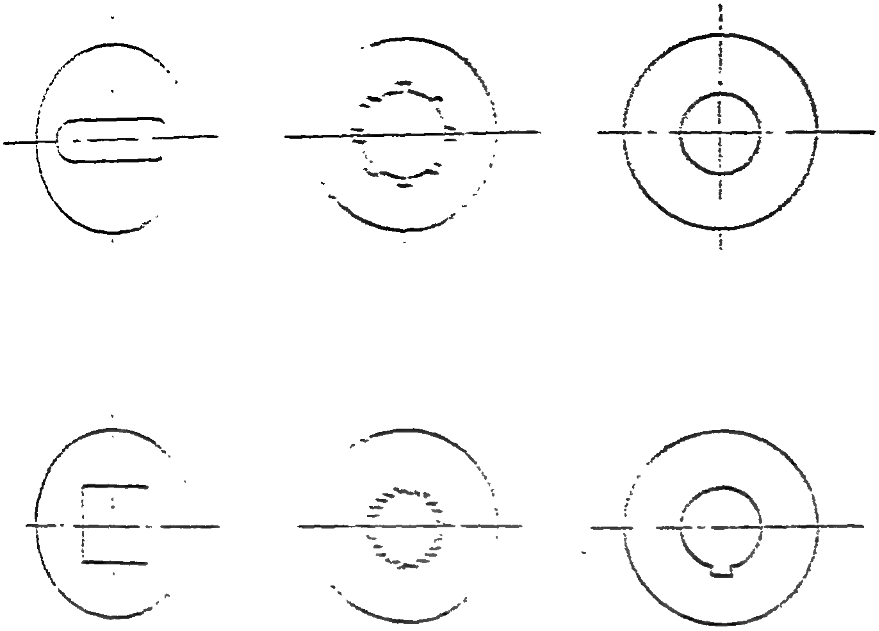


Fig. 13.03

could be used on brittle materials like cast iron and brass and a higher value for high strength ductile material. The value of steel may be chosen as 0·35 P.

Step 7 : The front rake (or hook angle) and relief are decided on the material of the workpiece. This is in consistent with the single point cutting tool. If the material is ductile use larger rake angle. For harder materials smaller rake angles are preferred. A good scheme on this selection is given below :

Cast iron	5°—8°
Brass	−5° to +5°
Hard Steel	5° to 10°
Steel	15°—20°
Aluminium	10°

Relief angle is usually kept at 3° and the land as 0·25 P.

Step 8 : The length of broach is fixed by the amount of metal removed by each tooth. In the case of broaching, it is not possible to remove larger amount of material by a tooth due to certain limitations. Amongst all the teeth, the maximum amount of metal is removed by roughing teeth which ranges between 0·02 to 0·075 mm per tooth. Finishing teeth remove material in the range of 0·01 to 0·02 mm/tooth. These figures refer to the structural steels, brass, cast iron and aluminium. With this information, if total depth of cut which a broach is going to remove in its cutting stroke is known, then the number of teeth and length of stroke could be fixed. This length shall be called effective length. The overall length is decided by fixing up the size of the pull end and the pilots.

Problem : Calculate the number of teeth in an internal keyway broach for finishing a key way to 12 mm wide and 6 mm deep in a boss of 40 mm length.

$$\begin{aligned} \text{Pitch} &= 0{\cdot}35\sqrt{40} \\ &= 1{\cdot}35 \times 6{\cdot}39 \\ &= 8{\cdot}62 \text{ mm} \end{aligned}$$

$\therefore$ Less than 6 teeth are in contact

For roughing cut let feed be 0·08 mm per tooth

Assuming that 10 mm depth being removed by roughing teeth, then

$$\begin{aligned} \text{No. of roughing teeth} &= \frac{10}{{\cdot}08} \\ &= 125 \end{aligned}$$

If the finishing cut is ·025 mm/tooth, the

$$\begin{aligned} \text{No. of finishising teeth} &= \frac{2}{0{\cdot}025} \\ &= 8 \text{ teeth} \end{aligned}$$

$$\therefore \quad \begin{aligned} \text{Effective length of broach} &= 133 \times 8{\cdot}62 \\ &= 1146 \text{ mm.} \end{aligned}$$

Manufacture of a Broach :

After the designer has worked out the complete details of the broach and prepared its working drawings ; the manufacture of the broach is taken up. It is very hard to describe a manufacturing process because each manufacturer has its own method to make a broach on special purpose machines. However, the important part to know is the heat treatment of the broach which differs from the conventional methods because of its extra long length. Since its diameter is very small in comparison to its length there is every likelyhood that the broach would get twisted during treatment. Also, in the same length while it is desired that the cutting edges acquire hardness, the shank should remain less hard and maintain toughness. The shank is covered with asbestos to avoid its heat treatment.

The broaches are suspended by wires inside a vertical furnace and heated slowly upto 800°C. The broach is then heated rapidly upto 1300°C for several minutes. It is removed and quenched in oil bath. The tempering is carried out at 500—550°C, when the broach is heated for several hours and then allowed to cool.

Besides heat treatment, the other important step in its manufacture is the inspection for broach of any twist and damage due to cracks during cooling.

In those cases where a more accurate control is required machines with electrohydraulic system is chosen. Machines with electrohydraulic systems cost more. The vibrations due to cutting action are less on vertical machines because the ram holds the tool rigidly.

Broaching machines are specified by the length of stroke in mm and the driving force in tons.

Advantages :

(*i*) A broach can produce a large number of components before it is replaced or reconditioned. The quantity ranges from 10000—15000 components.

(*ii*) If adopted for the manufacture of a large number of components, it proves to be an economical method as the cost of one component is less.

(*iii*) Since the operation is completed in one stroke of the tool it is a very rapid method of machining.

(*iv*) The cutting teeth are in action for a very short time and therefore, the heat due to machining and friction has practically no detrimental effect on the cutting edges.

(*v*) Highly skilled operators are not required.

(*vi*) A high degree of finish and close tolerances can be achieved.

Limitations :

(*i*) A broach is a costly tool. It is only used when its original cost can be "break-even" on the large number of components.

(*ii*) The special purpose machine is also a costly item. The machine has to be very rigid to control vibrations due to chatter.

(*iii*) Larger amount of metal can not be removed.

(*iv*) In usual cases, broaching can not finish a blind hole or flat surface which has any obstruction in the passage of the broach.

(*v*) It is necessary that the cuts are straight and parallel to tool travel.

(*vi*) Special care and fixture are necessary while broaching small and fragile parts.

(*vii*) Each job requires some sort of fixture.

QUIZ

Q. 1. Find out the power consumed in broaching a keyway in a cast steel pulley. The size of the keyway is 10 mm width $\times$ 5 mm depth $\times$ 30 mm length. If broaching is performed at 3 m/min and feeds for rough and finish broaching are respectively 0·10 mm/tooth and 0·03 mm/tooth, determine the size of the broach.

CHAPTER XIV

JIGS AND FIXTURES

TOOL ENGINEERING

The method of manufacture, the sequence of operations involved, the general nature of the equipment required and the fashion in which all this fits into the industrial process and plant as a whole is determined by *Process Planning Department* of the organisation for each and every component of the product to be produced in the works. This work is done by the Process Planner in consultation with the tool engineering section of the 'planning organisation. Process planning clearly indicates the requirements of jigs, tools, gauges and dies etc., in the appropiate columns, for efficient manufacturing of the product. Tool engineering section now analyses, plans, prepares and even supervises the construction and applicatian of this tooling equipment in the process planning sheet. The tooling equipment may comprise of the following :

(*a*) Cutting tools, tool holders and cutting fluids.
(*b*) Machine tools, particularly those of special type.
(*c*) Jigs and fixtures for machining.
(*d*) Gauges and measuring instruments.
(*e*) Dies for sheet metal working.
(*f*) Dies for forging, upsetting, cold finishing and extrusion.
(*g*) Dies for molding and die casting.
(*h*) Patterns for permanent moulds.
(*i*) Fixtures and excessories for welding, riveting and acsembling
(*j*) Abrasives, grinding compounds and fixtures for grinding, honing and finishing.

The process planner is a tool engineer of wide experience and has got knowledge of various manufacturing processes, equipment and is fully conversant with the design of at least one or a few mentioned above. Tool Engineer if he is other than Process Planner or Planning Engineer, is head of tool engineering section which consists of the following sub-sections :—

1. Tool design section.
2. Tool room section.

TOOL DESIGN

In the tool design office, tool designers are specialists in one or the other field. They accomplish the work with the help of draftsmen and final drawings are handed over to tool room foreman for starting the production of tooling equipment.

There are several ways in which a tool design office may be organised. One tool designer may be assigned to design all the tools for a certain part. This is known as the "Project Method" and is commonly found in small plants. Another method is known as the "Group Method" where each designer specialises in a particular class of tools like jigs, fixtures, dies or cutting tools.

The modern tool room may also be divided into three parts, fitting and bench work section, the machining section and the inspection section. In larger tool rooms the inspection of all work done in the tool room is carried out by a separate staff of inspectors whose duty is to make sure that all work conforms to the appropriate tool drawings and is within the limits required. In smaller tool rooms inspection of finished work may be carried by the works inspection department attached to the machine or fitting shops.

Tools and Tooling up

A tool can be defined as any device that is capable of working a material into a desired shape, holding it while it is being worked or measuring it after the work has been completed. Thus implements

used in all industries are covered by the above definition. In metal working however certain items are best known as tools. They are machine tools, accessories, cutting tools, fixtures, jigs, dies and gauges. Collets, sleeves and tool holders are also considered as tools.

The expression tool up or tooling up a component means to design and supply all tools like jigs, fixtures, cutting tools and gauges required for the manufacture and inspection of the piece including any structural alteration to machine tools which may be found necessary. In fact tooling up includes manufacturing the tools and sometimes setting them on the machine tools. Tooling up is complete only when the worker is ready to start production on the machine tool with all tools in place. Tooling up an automatic or a profile cutting machine is complete only when the cam or the former designed for each machine tool is set on the respective machine tool.

TYPES OF TOOLS

Machine tools : The machine tools are those kinds of equipment which are capable of reproducing themselves or other machines. The true machine tools are the lathe, milling machine, drill press, planer and shaper. They are known as universal machine tools. Others, such as the turret lathe, boring mill and multi-spindle drill press are modifications of the basic types and are known as special purpose machine tools. All other tools serve to augment and supplement the activity of these machines of industry. While designing tool any the designer must keep in mind the machine tool is to be used in. For this purpose certain data such as size and spacing of the slots on machine tool beds etc. must be available to the tool designer.

Templates : These are pieces of sheet metal shaped to the same profile as the piece to be fabricated and is used as a guide for

blacksmith to hammer a part to the required shape. A template may also be to the shape of a component but in addition has holes drilled through in similar position to those required in the finished pieces. Another type of template may be made from gauge plate and hardened. It can be clamped in the vise alongside the work piece which can then be easily filed to the same form. This method is often used when quantity is small to prevent expenditure on costly form cutters. All types of templates are used to save time when quantities are small or there is no money available for more expensive equipment.

Jigs : A Jig is a device in which a component is held and located for a specific operation in such a way that it will guide one or more cutting tools to the same position on any number of similar components which may be used in it. Jigs are used in only a few kinds of operations. Some common type of Jigs are : drilling and reaming jigs. More often jigs are classified according to features of construction.

Fixtures : A fixture is a device in which a component is held for a specific operation but the cutting tools are not guided. Fixture usually locates the work also. Fixtures may be classified according to the kinds of operations in which they are used. Some of the common types of fixtures are :

1. Milling fixtures.
2. Lathe and Turret lathe fixtures.
3. Boring fixtures.
4. Tapping fixtures.
5. Welding fixtures.
6. Assembly fixtures.

Essential difference between a jig and a fixture is that the former incorporates bushes that guide the tools employed, whilst the latter holds the component, that is the article being machined, with the cutters working independently of it.

Cutting Tools : Cutting tools are devices that remove metal in the form of chips from parent metal. Power is applied to them for producing definite work piece shapes. Cutting tools may be divided into two classes. Single point tools and multitooth cutters. Single point tools are those used in turning, facing, boring, shaping and planning. Multitooth cutters are the cutters such as drills, reamers, counter bores, milling cutters, broaches and saws. Cutting tools can be classified as standard or special kind or in some instances a combination of both. Standard tools are those that may be used interchangeably from one machine to another as tooling layouts are altered. Special tools are applicable to only one job. Economy of production results with the introduction of special tools. A form tool for instance used for producing a number of finished diameters simultaneously under suitable working conditions, would lessen considerably the time taken for producing the particular component..

Dies : Dies are used in many processes but the commonest are those which cut or shape sheet metal. Dies that cut sheet metal include stamping dies for blanking, and piercing. The other dies used in sheet metal fabrication work can be listed as trimming dies, cut off dies, shaving dies, forming dies, bending dies, drawing dies, embosing dies, coining dies, beading dies, sizing dies, burnishing dies. For hot metal forming close impression dies are used between the envil and upper ram of hammer. Upsetting dies are also used in upsetting machines for upsetting cold or hot stock. Die casting machine, also uses dies in which the metal is forced under high pressure. The two halves are opened after the metal solidifies and die casting component is obtained.

Gauges : A gauge is defined as a device for determining whether or not one or more of the dimensions of a manufactured part are with in specified limits. Gauges are also designed by tool designer in consultation with department. They are also manufactured in the tool room. Gauges are used both by inspectors and workers.

Tool Holders : Devices designed for locating and holding cutting tools are usually called tool holders.

USEFULNESS OF JIGS AND FIXTURES

The use of jigs and fixtures is extending and developing very fast. The quantity, type and complexity of jigs and fixtures used depend on the type of product and scale of production. The larger the output, the more economically feasible it is to employ jigs and fixtures. The less the volume of production, the more limited are the advantages to be expected by using jigs and fixtures. To mention a few points in their favour, the use of jigs and fixtures provides for the following :—

1. Eliminates the laborious marking out of each work piece before machining and consequently eliminates costly setting up according to the marking lines on machine tool beds.

2. Increases machining accuracy and ensures interchangeability because the work piece is automatically located without aligning on the machine tool and because the cutting tool is guided.

3. Increases, productivity due to increasing the speeds, feeds and depth of cut. This becomes possible in a jig or fixture due to high clamping rigidity.

4. Increases productivity due to increasing the workpieces simultaneously machined or the number of cutting tools operating

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4. Increases productivity due to increasing the workpieces simultaneously machined or the number of cutting tools operating

simultaneously as well as due to the reduction in handling time associated with setting up and aligning the work piece on the machine tool.

5. Saves operation labour.

6. Makes the use of lower skilled labour possible.

7. Decreases expenditure on quality control of the machine part.

8. Widens the technological capacity of machine tools *i.e.* increases the versatility of machining performed.

9. Either fully or partly automates the machine tool.

10. Facilitates assembly and also helps future up keep due to uniformity of manufacturing tolerances and promotes interchangeability.

The old machinist who laboriously marked off parts has gone, to be replaced by the tool maker responsible for the manufacturé of jigs and fixtures. It must not be assumed however that the system of employing jigs etc. is infallible, because in the castings which vary considerably in form, much trouble often occurs. Adjustable supporting pins or jack pins are used to properly align castings or forgings. Some times centre lining or roughly marking out important points of the casting and then locating them in fixture also becomes necessary in some automobile components, cylinders etc.

UNDERLYING PRINCIPLES OF JIGS AND FIXTURE DESGIN

Jig and fixture design is based upon a number of fundamental principles which must be understood properly and their valtue appreciated before work is commenced on actual designs. While the designer will encounter new problems on every new design these underlying principle will be found to be same in every branch of engineering. With any design the aim should be simplicity. As the designer gets experience in job, his design will become more efficient and he shall be conforming more and more to these principles. Some of the principles are discussed below :—

1. Reduction of idle time :—Method of location and clamping should be such as to reduce idle time to a minimum.

2. Rigidity :—Ensure that the jigs and fixtures are rigid enough. Milling fixtures should be specially robust in design because they have to bear intermittent cuts also which can cause distortion of the fixture body and also give rise to vibrations. Cast iron which absorbs shocks more readily is recommended for fixture bodies.

3. Clearance between jig and component :—There should be plenty of clearance between the jig and the component to take care of variations in dimensions in mass manufacture. Castings some times differ considerably in dimensions. Such a clearnce is also necessary for chips to pass out through the opening between component and jig plate rather than choke the jig bush while trying to come out through it.

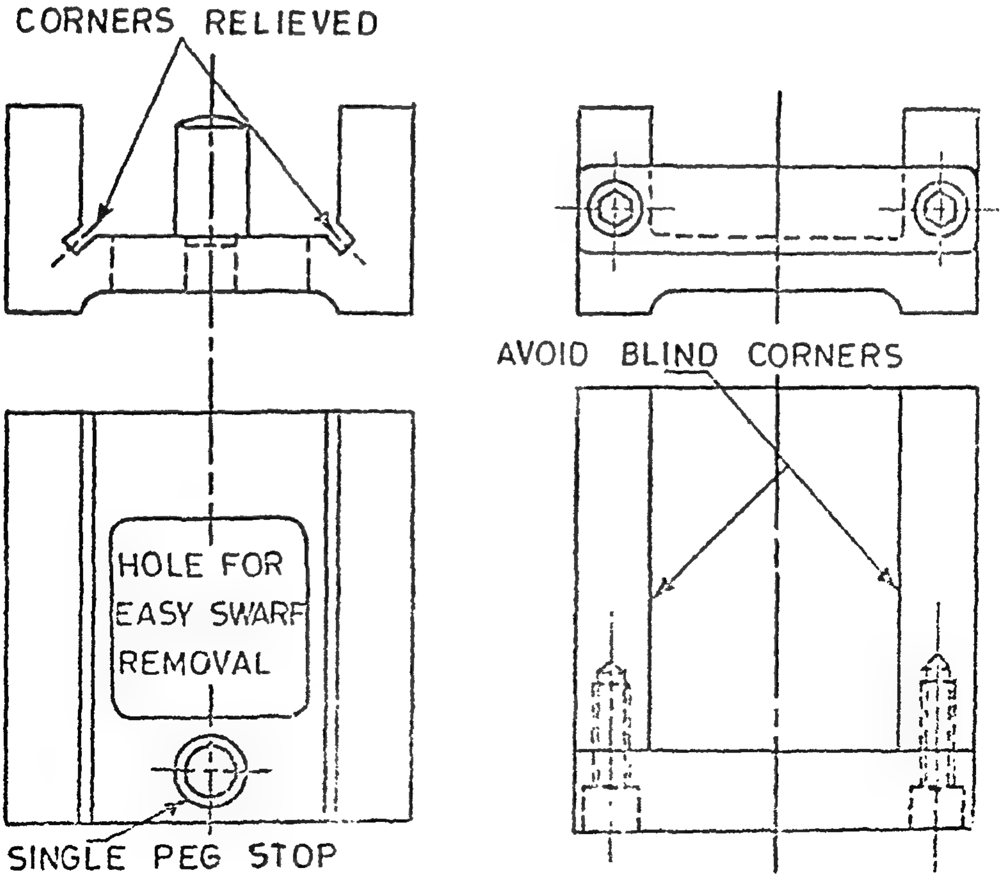

Fig. 14.1 Jigs with and without swarf clearance provisions

4. **Swarf Clearance** :—In small drill jigs, the importance of providing good swarf clearance is particularly important. The awkward little corners that cannot help but collect small chips and swarf must be avoided if an accurately drilled component is required. (fig. 14·1) In larger drilling jigs and particularly those made from castings adequate swarf clearance can be provided by designing the jig with cored holes at points where swarf is likely to accummulate. These cored holes also serve to let the coolant if used, to flush minute particles of swarf out of the jig.

5. **Locating Points and Supports** :—(*i*) Locating and supporting surfaces should wherever possible be removable. Generally surfaces should be of hardened material. (*ii*) Make sure also that locating points are clearly defined and are not such that they are likely to hold swarf swept from adjacent positions. The use of large flat machined faces for locating purposes should be avoided as they require more cleaning between components and only serve to collect unwanted chips and coolant (fig 14·2) (*iii*) For easy removal of worn

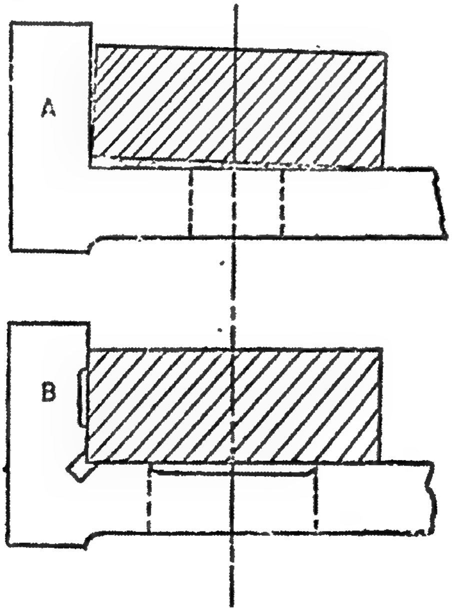

Fig. 14.02 (*a*) Faulty location (*b*) Location improved with relieved machined surfaces

out locating or supporting pins, these should be fitted into through holes and not blind holes. (fig. 14.3)

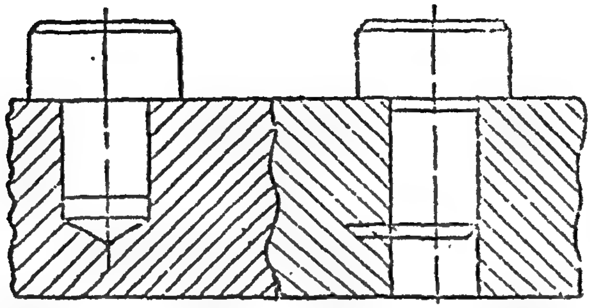

Fig. 14.3

6. **Easy loading and unloading of the Jig** :—The process of loading and unloading the component should be as easy as possible. On heavy components the operater should be able to slide his component into the fixture.

7. **Clamping** :—(*a*) Clamping should always be arranged directly above the points supporting the work. If this rule is disregarded, it will result in the springing of the work, causing it to be machined in a distorted position, resulting in inaccuracies after the work is removed from the jig and is released from clamping strain, resuming its original posi- tion.

(*b*) Fibre pads should be riveted to clamp faces where metallic contact with the work would cause damage.

(*c*) Arrange all clamps and adjustments on the side of the fixture nearest to the operator whilest he is loading and unloading the component.

(*d*) Design the clamping arrangements in such a way that they can be easily and quickly removed clear of the work and avoid the necessity for lengthy unscrewing of nuts.

(e) Do not rely on the clamps to hold the work against the cut but arrange fixed stops which will take the direct thrust of the cutters.

8. Fool proofing :—As these jigs and fixtures are used by mostly unskilled labour, care should be taken to ensure that components can be loaded into position correctly. Pins and similar devices can be often driven into the face of the jig to prevent the components being loaded incorrectly.

9. Design for Safety :—All sharp edges should be removed from details forming the jig or fixture unit. Head of Allen bolts which are extensively used in built up jigs should not protrude above the surface of the dies. These should go in the recess provided for the purpose. Heavy box jig if required to be turned should be provided with trunions to reduce operator labour.

10. Components should be Ejected :—Wherever possible, particularly on heavy components arrange the jig so that when unclamped the component is either partially or completely ejected, so saving the operator the need for hammering or struggling with the piece. Air operated fixtures lend themselves very well to this treatment.

11. Spring Locations :—The number of locations on any rough component should never exceed three in any one plane. The component will sit on three points without rocking. Should it be necessary, however for further supports to be provided these should be spring loaded so that after the component is on the three fixed positions, others where necessary will automatically rise to touch the component through the medium of the springs. These spring locations can then be locked in position.

12. Jig Base:— A jig which is not bolted to machine table must be provided with four feet instead of whole bottom surface lying on the machine table. In this way the jig will rock of it is not standing square on the machine table due to some chip under one of the feet and warn the operator. (fig. 14.4)

13. Accuracy :—All operations produce variations in their results. Jig or fixture designer has to determine what variations can

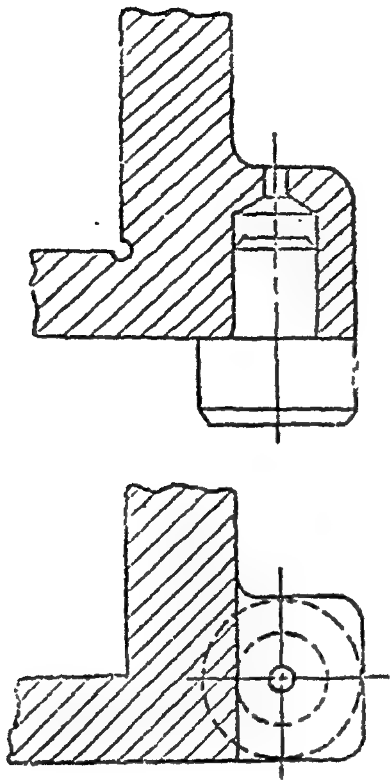

Fig. 14.4. One Type of Jig Foot

be permitted in an operation. The locating and clamping system should be so designed as to keep the variations with in the desired limits. Variations arise from the following causes :—

1. Variations in the dimensions of the workpieces coming to an operation.
2. Variations in material conditions.
3. Defects in tools and machines.
4. Wear.
5. Deflection.
6. Thermal expansion.
7. Dirt, chips and burrs.
8. Errors of human judgement, limits of perception and deficiencies of skill.

Inorder to achieve desired accuracy, the means of controlling each of these causes of error must be understood by the designer.

Wear : Means of controlling errors due to wear, dirt, chips, burrs, have been discussed at appropriate places. It is usually desirable to insert wear resisting materials in areas subjected to wear. Cutting tools and dies also wear. They should be replaced when the wear allowance is finished. Wear resistance surfaces should be as small as possible.

Deflection : Deflection is always present where forces of any magnitude bear upon physical objects. Positive measures must be taken to protect against deflections. Clamps should never be applied to an over hanging section of a work piece but instead should bear directly over fixed locating rests or stops if possible. In up-milling the cutter tends to deflect the fixture up in the middle. Proper thickness should be provided to the fixture in such cases.

Thermal expansion : Thermal expansion may be appreciable when considerable energy is dessipated into heat in a manufacturing operation. The effect upon accuracy of large expansions and contractions is obvious. But even small temperature changes may spoil the accuracy obtainable in precision work. A skilful operator working on a sensitive jig boring machine can space two holes to within one or two thousands of inch. But the drilling and boring of holes introduces heat. A rise in the temperature of the work piece of 10° is not unusual. In a distance of 250 mm an expansion of ·015 mm in iron or steel takes place and adds an appreciable error to the results. The results of the thermal expansion are most pronounced where dissimilar metals are involved. The most effective manner of minimizing the effects of thermal expansion is to moderate the temperature differential. Temperature can be controlled by having controlled room temperatures and by ample supply of coolant.

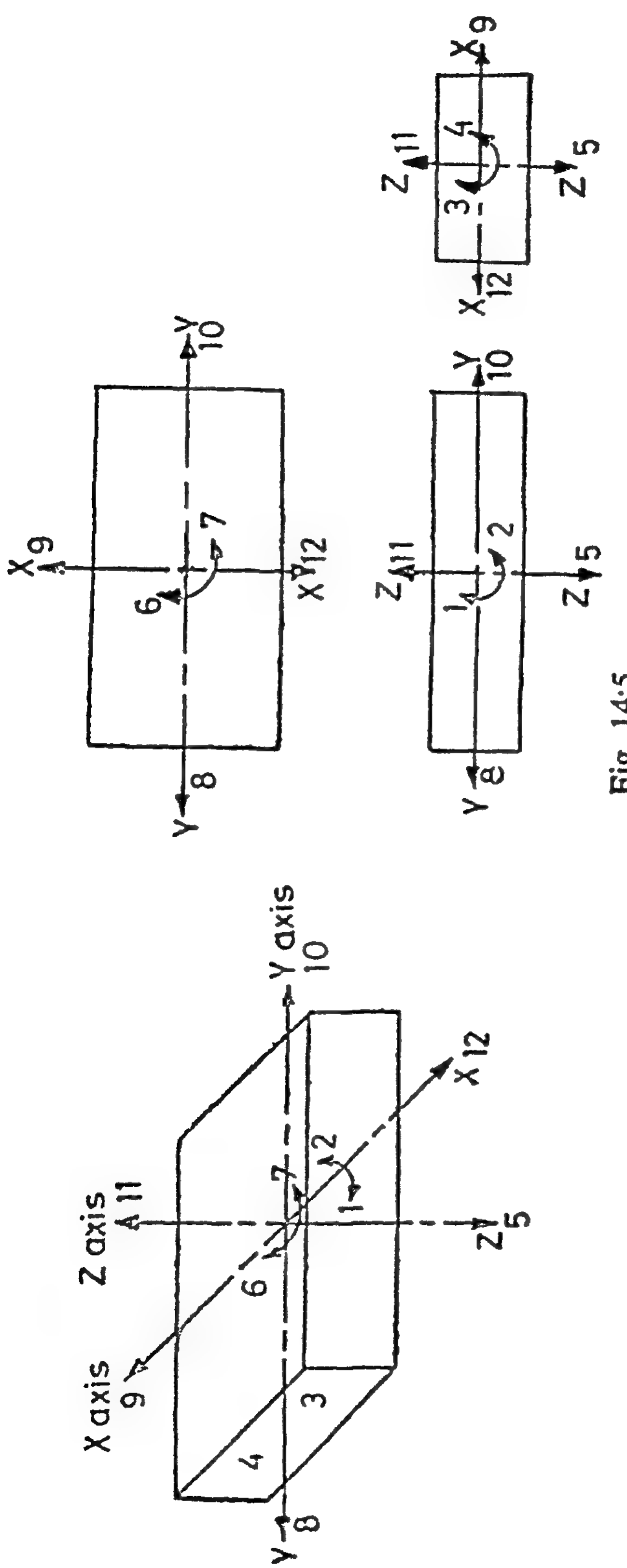
X axis
9
Z axis
11
Y axis
10
X 12
Z 5
Y 8
1
2
3
4
5
6
7
X 9
X 12
Y 10
Y 8
Z 11
Z 5
X 12

Fig. 14·5

14. Jig Bushes :—Drills, reamers and boring bars should be guided to the desired point through bushes fixed in the jig plates. If these tools are guided through holes in the plate only then the full plate will have to be hardened which is not a practical proposition in large jigs. Where as the bushes when worn out due to the friction of coming out chips can be replaced at intervals.

LOCATING AND CLAMPING

Twelve degrees of freedom :

A work piece in space free to move in any direction can have twelve such directions. It can move in either of two opposed directions along three mutually perpendicular axis and may rotate in either of two opposed directions around each axes, clockwise and counter clockwise. Each direction of movement is considered one degree of freedom. Thus there are twelve degrees of freedom for any workpiece in space. To locate a workpiece accurately it must be confined to restrict it against movements in any of the twelve degrees of freedom except those called for by the operations. Workpiece can be accurately and positively confined in a jig or fixture if the above condition is satisfied. The twelve degrees of freedom as applied to a rectangular piece are shown in the figure 14.5.

Principles of Location :

1. 3-2-1 Method of Location :—A work piece can be positively located by means of six pins so positioned that collectively they restrict the work piece in nine of its degrees of freedom. This is known as six point location method. Now three of these pins are in the first plane and two in the 2nd plane perpendicular to the first and one in the third plane perpendicular and adjacent to both 1st and 2nd planes. Thus this method of location is known as 3-2-1 method of location also. The figure 14.6 shows the prism resting on three pins ABC. The faces of three pins supporting the prism form a plane parallel to the plane that contains the x and y axis. The prism cannot rotate about the x and y axis and it cannot move downward in the direction of freedom 5. Therefore freedoms 1, 2, 3, 4 and 5 have been restricted.

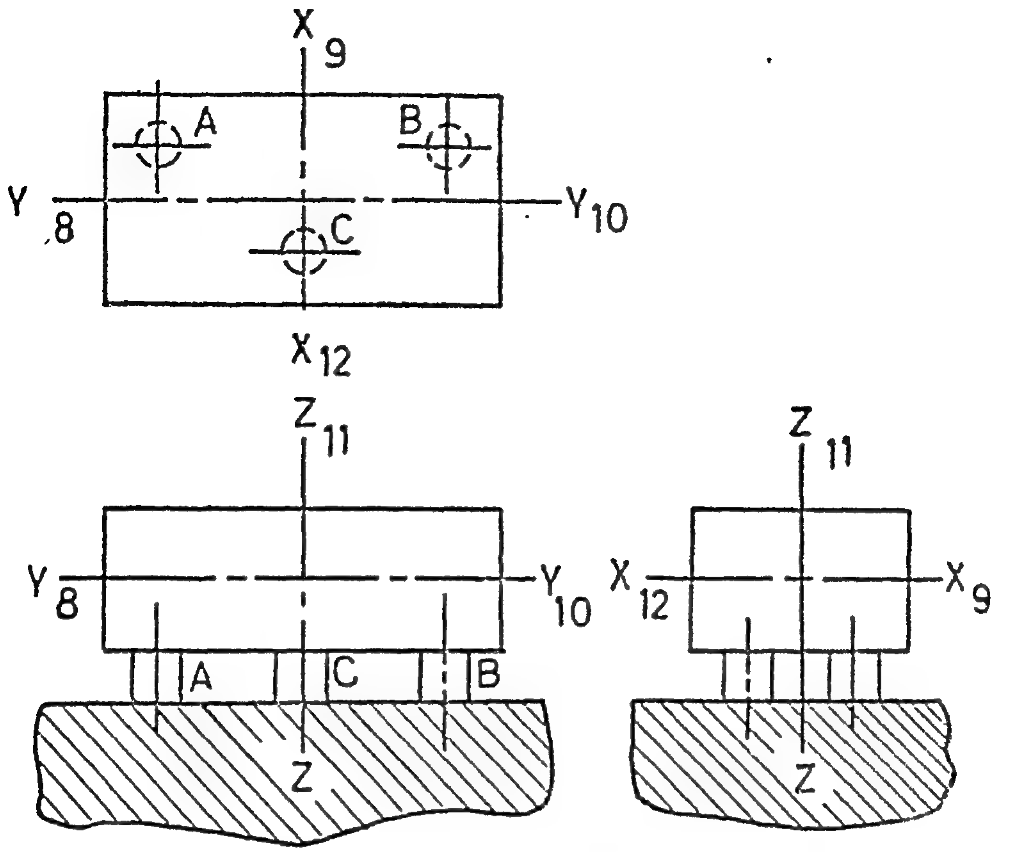

Fig. 14.6 Three pins restrict five degrees of freedom.

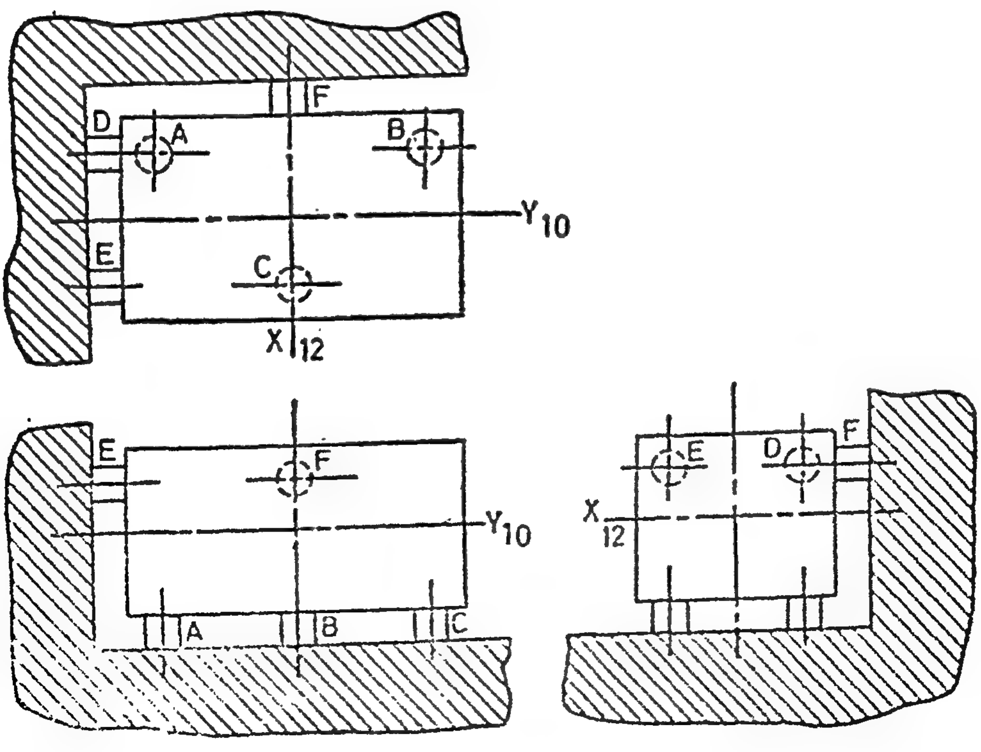

Fig. 14·7 Three more freedoms restricted

In figure 14.7 two additional pins *D* and *E* whose faces are in a plane parallel to the plane containing the x and z axis prevent rotation of the prism about the z axis. It is not free to move to the left in the direction of 8. Therefore 6, 7, 8 have been restricted and the prism cannot rotate.

With the addition of pin *F* as shown in the (fig. 14.8) freedom 9 is restricted. Thus by means of six locating points three in a base plane, two in a vertical plane, and one in a plane perpendicular the first two, nine degrees of freedom have been controlled. The remaining three freedoms are controlled by means of clamping devices

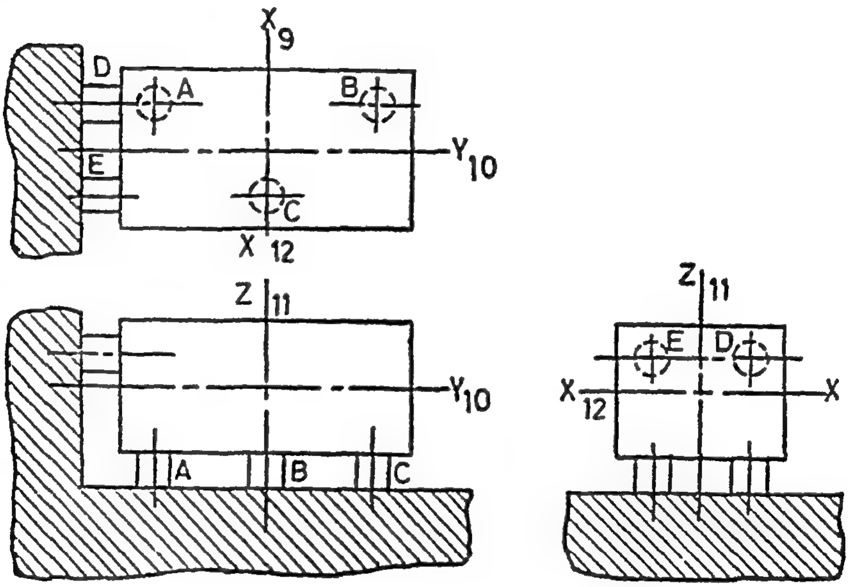

Fig. 14·8

which can take care of any variation in dimensions of work piece in the direction of freedoms 10, 11 and 12.

Hence 3-2-1 principle should be used to locate work pieces.

2. **Principle of Least Points** :—Points more than necessary should not be used to secure location in any one plane. However if more are used such as for finished surfaces, the extra ones should

only be inserted because they serve a useful purpose and care must be taken that they do not impair the location. Extra supports if needed should be made adjustable also.

3. **Principle of Extreme Positions** :—Locating points should be chosen as far apart as possible on any one work piece surface. Thus, for a given displacement of any locating point from another, the resulting deviation decreases as the distance between the points increases.

4. **The Principle of Mutually Perpendicular Planes** :—The most satisfactory locating points are those in the mutually perpendicular planes. Other arrangements are possible but not desirable. Two disadvantages result from locating from other than perpendicular surfaces :

(*a*) the consequent wedging action tends to lift the work piece.

(*b*) the displacement of a locating point or a particle (chip or dirt) adhering to it introduces a correspondingly larger error. In Fig 14·9 the introduced error T is projected to

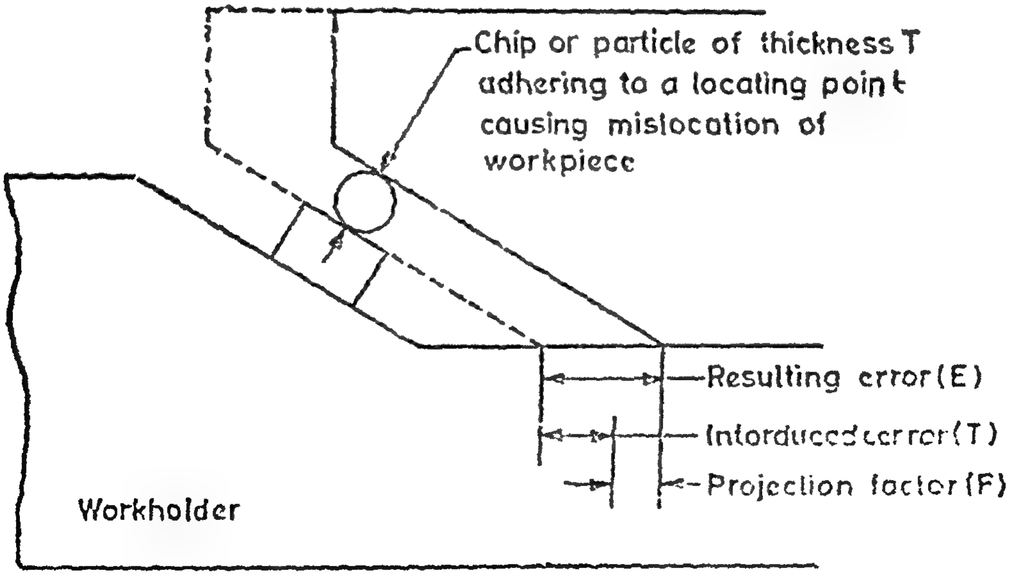

Fig. 14·9

become the resulting error E. The projection factor F is

zero when the locating surfaces are perpendicular and increases as the angle between them becomes more acute.

5. **Location of Accurate Work** :—When accuracy is required, *do not attempt to locate from a hole or position previously machined*, on which a wide tolerance is permissible, but consider the advisability of having the tolerance tightened so that the required result on subsequent operations may be obtained.

6. **Small Locating Surfaces** :—The benefits gained from small locating surfaces such as on rest buttons, supporting pins or cylindrical locators aer (*a*) less time for cleaning (*b*) reduced chance for lodgement of disturbing particles, (*c*) a more realistic approach to the mean plane of a rough surface, (*d*) some saving in material and labour. Only thing against this benefit is greater rate of wear causing early replacements. Therefore, these surfaces should not be too small which also create high specific pressure on the workpiece at such points.

6. **Replacement a necessity** :—All locating points which require replacement due to wear and tear should be easily replaceable or repairable. A vee locator should be easily built up with the help of two dowel pins and two allen screws. Pins should be driven into through holes for easily driving them out to replace *V*. Rest buttons and cylindrical locators should similarly be also pressed into through holes. (fig. 14.10).

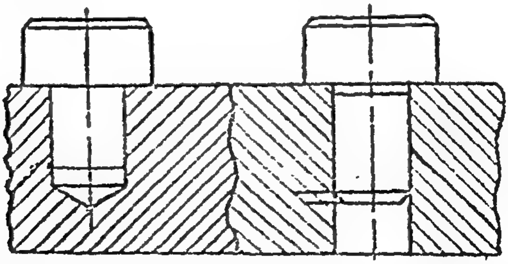

Fig. 14.10

8. Swarf Clearance :—All corners that collect small chips and swarf must be avoided by releiving them. Under cut should be provided to all locators where they create a corner with the surface to which they are fixed. Numerous kinds of designs in these locators are available to avoid blind corners at some of these points. (fig. 14·11 and 14·12).

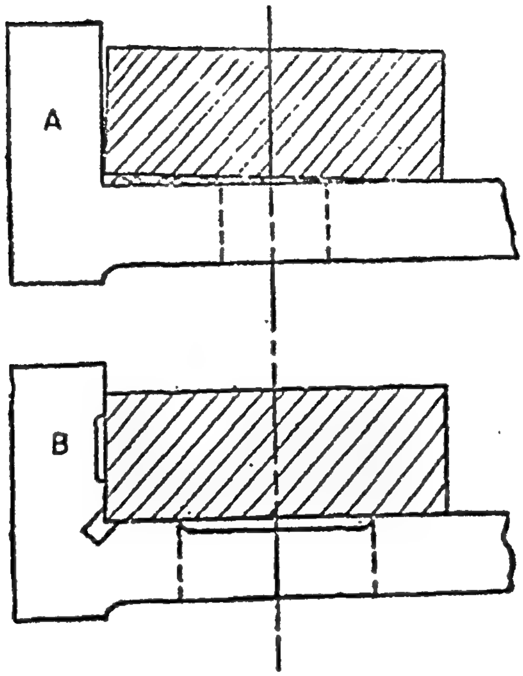

Fig. 14·11

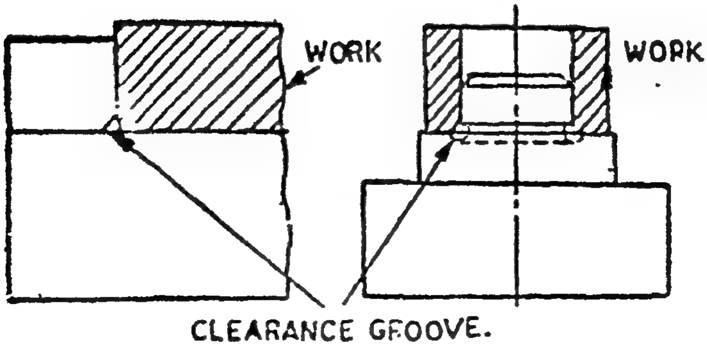

Fig. 14·12

LOCATING DEVICES

1. Jacks and Supporting Pins :—It is not always advisable to clamp the work directly to either the base or one of the walls of the fixture. Perhaps the component is not machined at those places where it is most convenient to effect the clamping. In such instances *jacks or pins are raised to support* the work beneath the clamps. These jack or pins are of various type such as :—

1. Support pins or rest buttons (Fixed type) Fig. 14·13.
2. Support pins or rest buttons (Adjustable type) Fig. 14·14

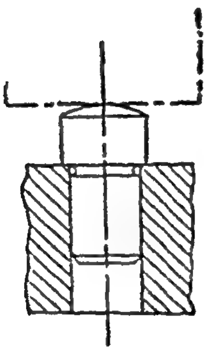

Fig. 14·13

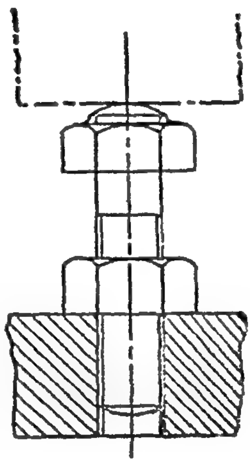

Fig. 14·14

3. Supporting pads.
4. Jack pins (*a*) Wedge type.
   (*b*) Spring jack pins (Fig. 14.15)
5. Jack screws.
6. Stop pins.

All types of pins except No. 6 support the work and are loaded in compression but pins are used some times as stop pins also for flat surfaces where they are under shear. Here they save some material of the jig wall but they cannot be very effective when force of the cut is to be borne.

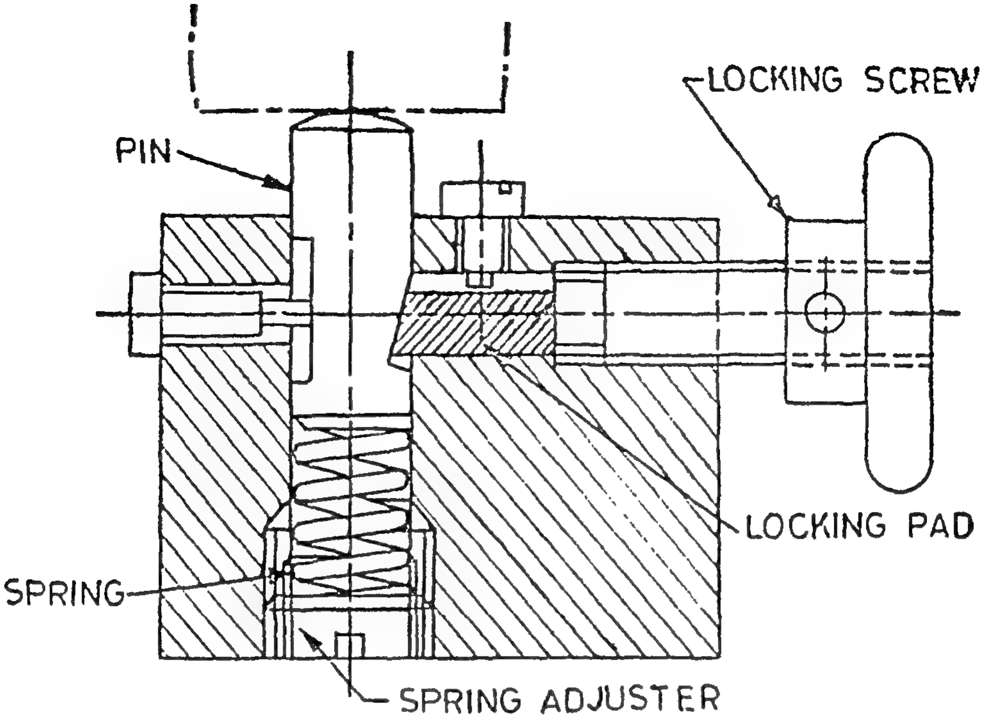

Fig. 14·15

All supporting pins or rest buttons can be further classified as :

1. Round headed.
2. Flat headed.

Round head rest buttons are used for locating a rough surface. In this case the area of contact between the buttons or work piece will approach a point. This will result in more definite location and will ensure high stability of the work piece.

Flat rest bottons or pads are used for locating flat machined surfaces. It is not advisable to use round head rest bottons in this case for the following reasons :—

(*a*) In point contact between the button and workpiece the button surface wears rapidly and its height is changed. Usually when a work piece is located on machined surface accurate location is required.

(*b*) If the area of contact on the work piece surface is small, an impression or dent may remain on the surface due to high specific pressures produced in work clamping.

The working of jack pins can be easily understood from the drawing. Fig. 14·15 shows the spring jack pin which automatically positions itself and is raised into position by an compression spring situated beneath it. Upon assuming its correct relative position, the pin is prevented from dropping by turning the hand nut, which forces a pin on which an angle is machined, against a flat of the same angle provided in the jack pin itself. To prevent the locking pin and the jack pin from getting out of position, a keyway into which a small dowel peg is screwed is miled in each of these parts. This type of jack is the most generally used and will be found to be very affective.

Wedge type jack pin is a further common type but it is not automatic. The setting of the jack pin is done by pushing the hand nut and consequently the taper pin attached to it, towards the jack pin : the jack pin riding up the taper provided, is raised until it touches the work.

2. **Cylinderical Locators or Location Pins** :—When reamed or finely finished holes are available for positioning purposes the types of locating pins most generally used are :—

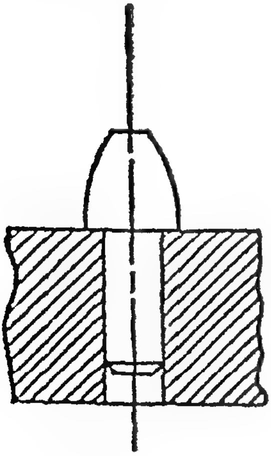

Fig. 14·16

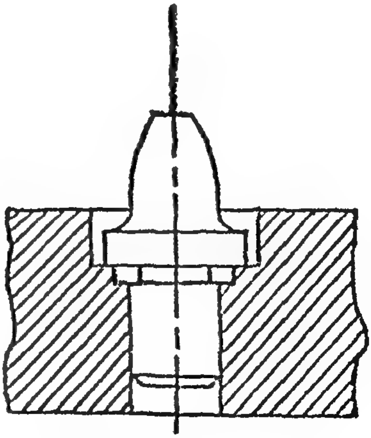

Fig. 14·17

(a) Plain locating pins (Small holes) (Fig. 14·16)

(b) Plain Locating pins with flange (Small holes Fig. 14·17)

(c) Locating pins for large holes (Fig. 14·18)

The shoulders are provided in all the three types so that the pin may not be pushed into the fixture by the work. The pins in fig. 14·16 and fig. 14·17 are pointed in order that the operator may more readily apply the work to the correct position. These pins are sometimes called bullet nosed locators also due to the shape of the pin.

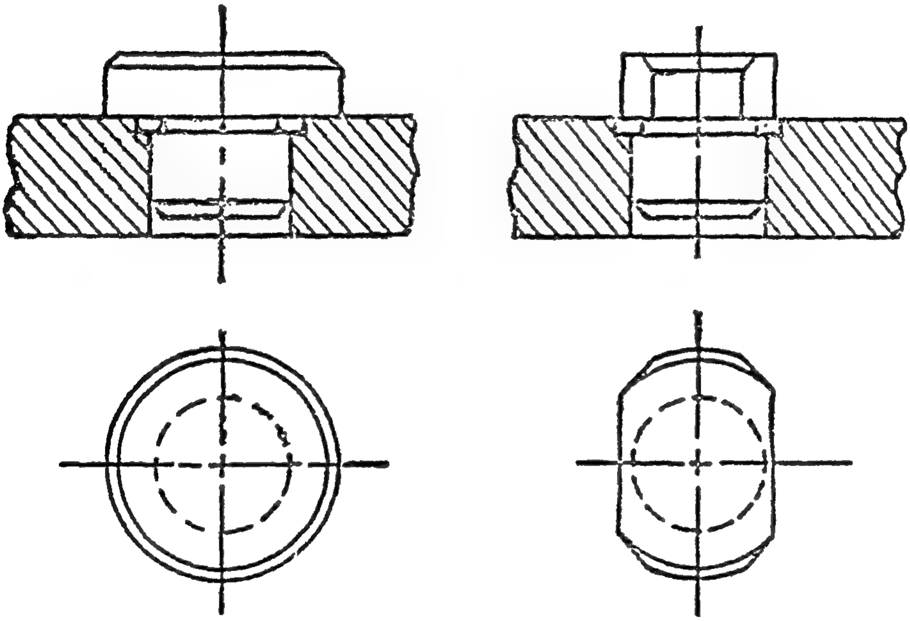

Fig. 14·18

When the components, or parts are of a heavy nature and it is only possible to slide them into the jig and fixtures it is of advantage that disappearing pins be fitted. By movement of the hand lever it is possible to lower the locating pin into the fixture to facilitate the loading and unloading of the work and then to raise it into position as required. This is affected by means of an eccentric turned on the operating pin which fits into a slot in the locating pins.

3. Conical Locators :—If the diameter of the hole is subject to considerable variation as it usually is in a semifinished or rough

piece, the lateral movement of any piece with respect to the locator is likely to be quite much. To overcome this variation and centralize the hole a conical or tapered plug may be used instead of a straight plug. Sometimes there is spring below the plug so that the job will always rest on the buttons also.

4. **Diamond Pin Locator** :—It is possible to accurately locate a workpiece with two round pins but allowances must be made for the variations encountered in hole sizes and locations. For instance the distance between holes *A* and *B* Fig. 14·19 will vary to the extent of tolerance *X*. Similar the distance between pin *A* and *B* in Jig or fixture has a tolerance *Y*. For accurate location there should be an allowance between pin *A* and hole *A* of only a few ten thousandths of an inch. But if pin *B* is a complete cylinder (same as

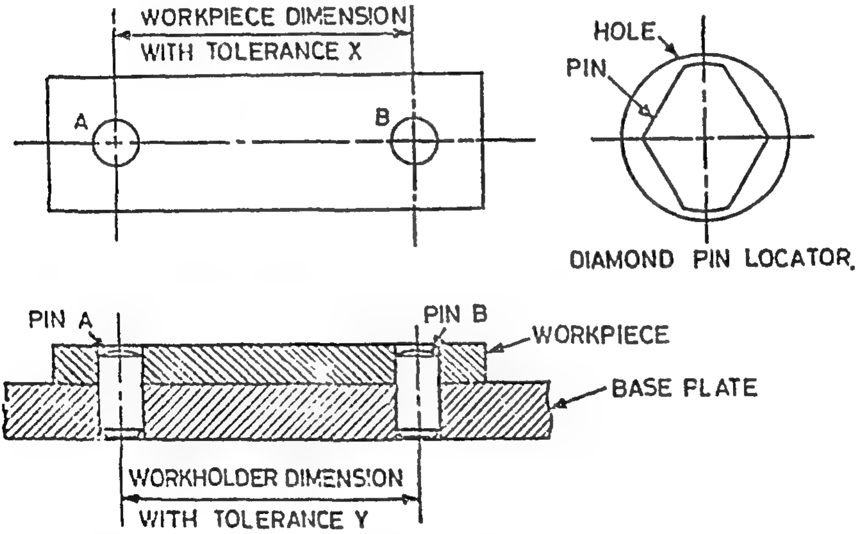

Fig. 14·19

pin *A*) the allowance between pin *B* and hole *B* must be atleast as great as the sum of tolerances *X* and *Y*. This is necessary for the pins to engage holes within the permissible tolerance *X*. Extreme cases occur when both hole and pin centre to centre dimensions are at maximum and minimum conditions. As a result there will be large allowance between the hole and pin at *B* in a direction $\perp$ to

centre of two pins of the fixture. This will permit an undesirable amount of radical rotation around the axis A and will defeat the purc for which pin B is intended. To achieve more accurate radial location B is made a diamond pin as shown in the fig. 14·20. It is relieve on two sides to allow for variations in the X direction and has two cylindrical portions to locate in the Y direction. The minimum radial movement of the workpiece occurs when the diameter, of the cylindrical portions of the pin is smaller than the diameter of the hole by the allowance necessary to slip the minimum size hole over the pin (fig. 14. 20)

To allow for variation in the position of the hole, the contact width w must be short enough to leave a clearance $S|2$ such that S is equal to or greater than the sum of the tolerances X and Y of the

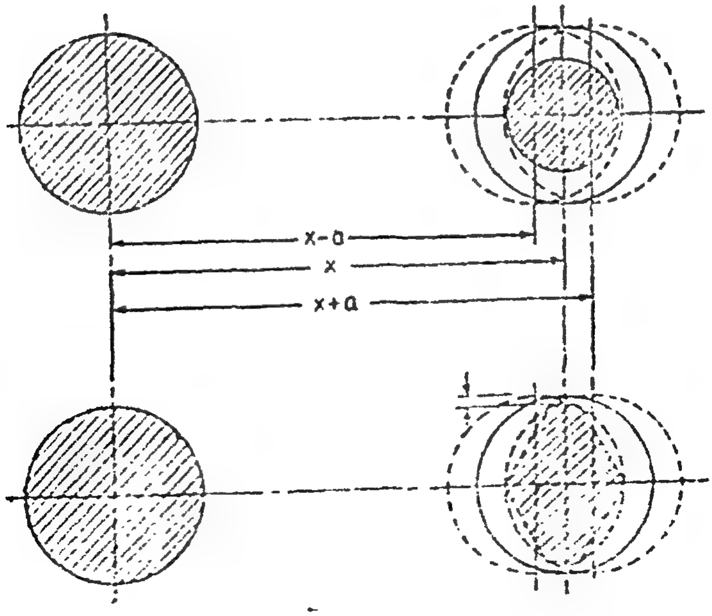

Fig. 14.20

piece, the lateral movement of any piece with respect to the locator is likely to be quite much. To overcome this variation and centralize the hole a conical or tapered plug may be used instead of a straight plug. Sometimes there is spring below the plug so that the job will always rest on the buttons also.

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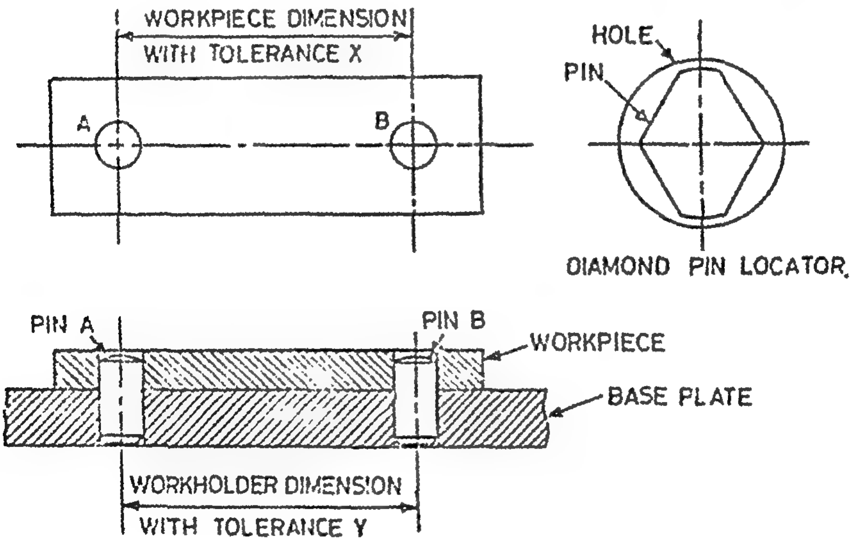

Fig. 14·19

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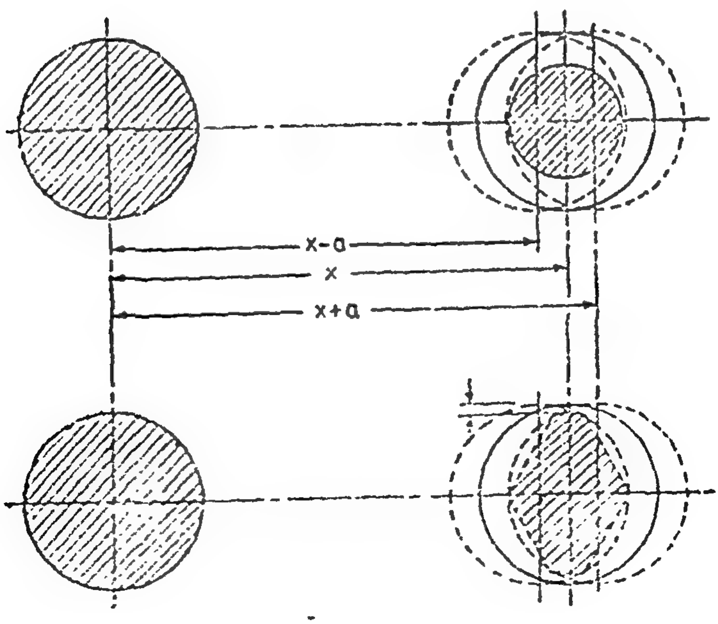


Fig. 14.20

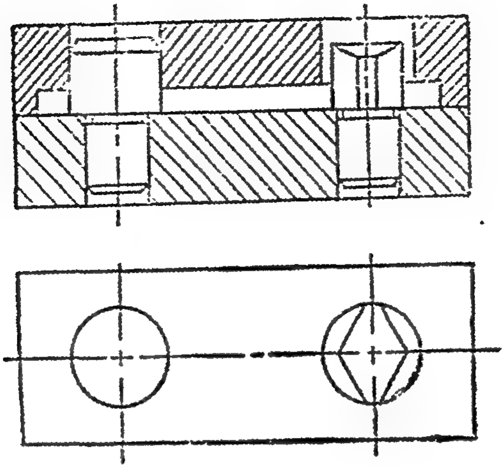


Fig. 14.20A

centre distances between the holes and between the pins. (Fig. 21)

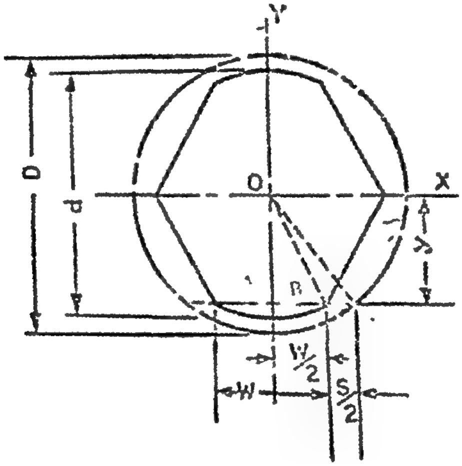


Fig 14 21

From the two triangles, *OAB* and *OAC*, the following relationships are evident :—

$$y^2=\frac{d^2}{4}-\frac{w^2}{4}=\frac{D^2}{4}-\frac{w^2}{4}-\frac{2wS}{4}-\frac{S^2}{4}$$

Where *D* is dia of hole *B* and *d* dia of pin at cylindrical portions.

Thus $2ws = D^2 - d^2 - S^2$

$$w = \frac{(D+d)(D-d)}{2S} - \frac{S}{2}$$

$$= \frac{[2D-(D-d)](D-d)}{2S} - \frac{S}{2}$$

$$= \frac{2D(D-d)}{2S} - \frac{(D-d)^2}{2S} - \frac{S}{2}$$

But $D-d$ is small, of the order of ·025 mm. Therefore $(D-d)^2$ is still smaller and the term $\frac{(D-d)^2}{2S}$ is negligible in comparison with other terms. Thus

$$w = \frac{D}{S}\ (D-d) - \frac{S}{2}$$

For hardened steel pins, acceptable practice permits a width as small as 1/8 of the nominal diameter of the hole in which it locates but not less than about 0·5 mm.

Vee Locators :

A component incorporating a circular or a semi-circular profile may be located by means of a Vee block. There are three types of locators.

1. Fixed type vee locators.
2. Sliding type vee locator.
3. Cam operated sliding type vee locators.

Vee blocks may be used for clamping as well as locating if vee faces are inclined up to about three degrees. Vee-blocks usually have an angle of 90°.

Fixed vee locator is shown in (Fig. 14.21). It is secured to the jig body by means of screws and dowels. Three degree taper ensures

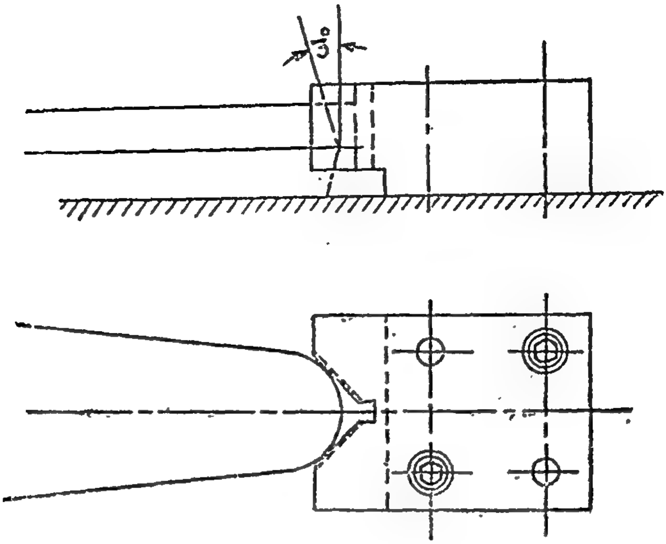


Fig. 14.21 (a)

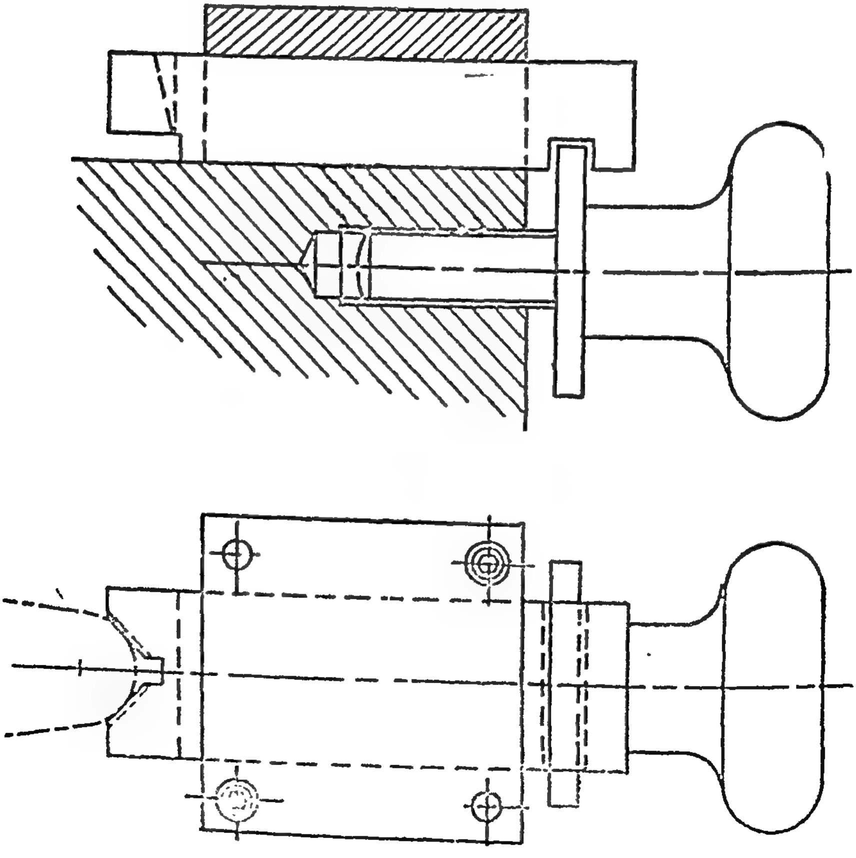


Fig. 14.22

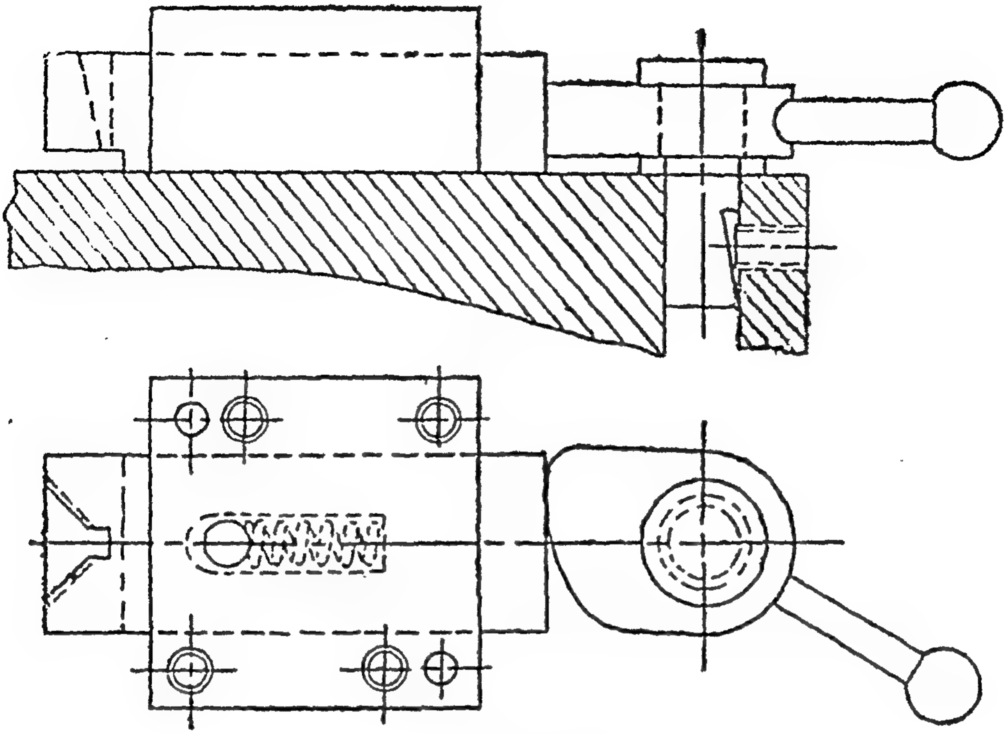


Fig. 14.23

that the top of the vee over hangs the component for clamping purposes. The two types of sliding vees are shown in the figures 14·22, 14·23. Former is actuated by means of a hand operated screw where as the latter is cam actuated. The spring bearing against the fixed pin is fitted to return the vee block when the cam is released. All sliding parts should be made of steel and hardened and ground. The bottom of the vee should be slotted to remove the sharp corner.

Mean Locators or Centralisers :—Some times the radial locator is a button against which one side of a wing of the part bears. If this is a rough part, the centre of the section may vary considerably in its location from piece to piece. Even if the sides are finished, some variation can be expected. If it is necessary to cut a groove, the or drill one or more holes in line with the centre of the wing, manner of location is obviously inadequate. What is needed is a means of setting the centre of the section in a definite position each time a piece is located. This is known as centralization. A centralizer is a device that forces two and sometimes more opposed points into positions where they are equidistant from a fixed point. Centralizer locates the centre point between the spots it contacts. At

the same time a centralizer performs a certain clamping function. A few examples of the use of centraliser are given in fig. 14.24 and fig. 14.25.

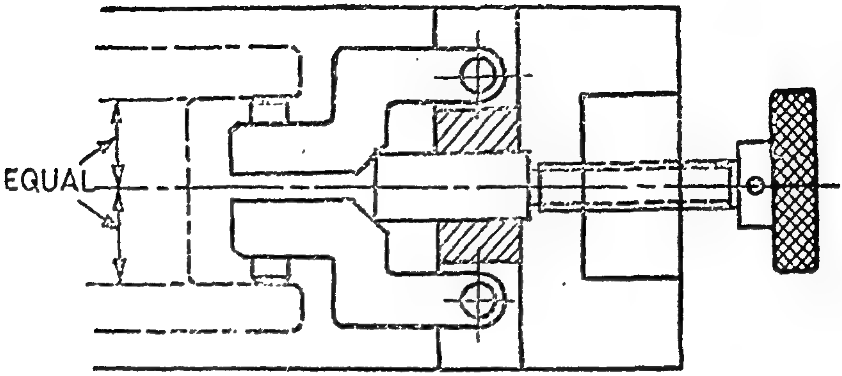


Fig. 14.24

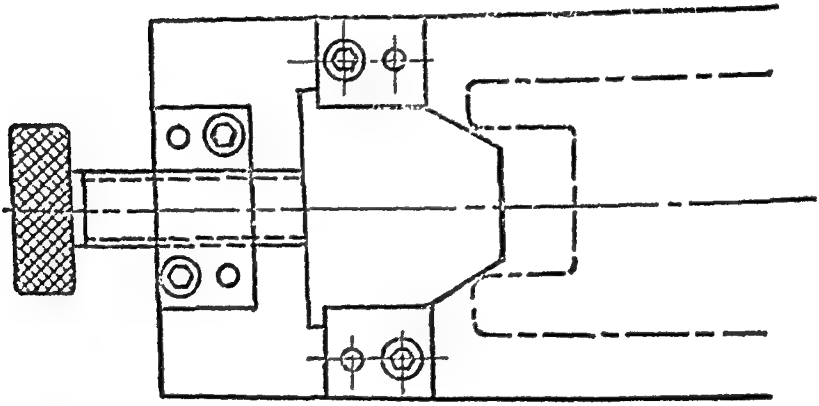


Fig. 14.25

Clamping devices : Some sort of clamping device is an essential part of both jigs and fixtures. Clamping may be simple or complex but it must fulfill the following essential design requirements :—

1. The clamping devices must hold the workpiece rigidly against all disturbing forces.

2. It should also keep the work piece firmly incontact with locating pins or surfaces.

3. The time required to loosen the clamp on the workpiece and tighten it again on next piece should be minimum. Compression spring should be used to lift the clamp away from the workpiece.

4. The clamping devices when subjected to vibrations, or heavy pressure must be positive and should not distort.

5. The clamp while holding the workpiece should not damage it. Thick section should be chosen for bearing clamping forces.

6. Placement of nut or handwheel should be such as to control the amount of pressure to be exerted on the workpiece.

7. The movement of the screw, lever or cam of the clamping device whether of the rotary or reciprocating type should be strictly limited to make the device quick acting.

TYPES OF CLAMPING DEVICES

1. Strap Clamp :

Strap Clamp being simple and economical is popular device for clamping. Strap clamp consists of a heel pin, toe, stud, spring, spherical washer, a plate or strap and nut Fig. 14·26. There are several modifications of the strap clamp based on the design of the heel. Some times the heel is an extension of the jig. At other times it is extension of the strap. Heel can be fixed to body of the jig as a separate piece and it can be made adjustable in height also. All the modifications can be listed as :—

1. Solid heel clamp.
2. Loose guide heel clamp.
3. Clamp using heel in casting. (fig 14·27 *a*).
4. A standard strap clamp providing adjustment of heel. (fig. 14·27 b)

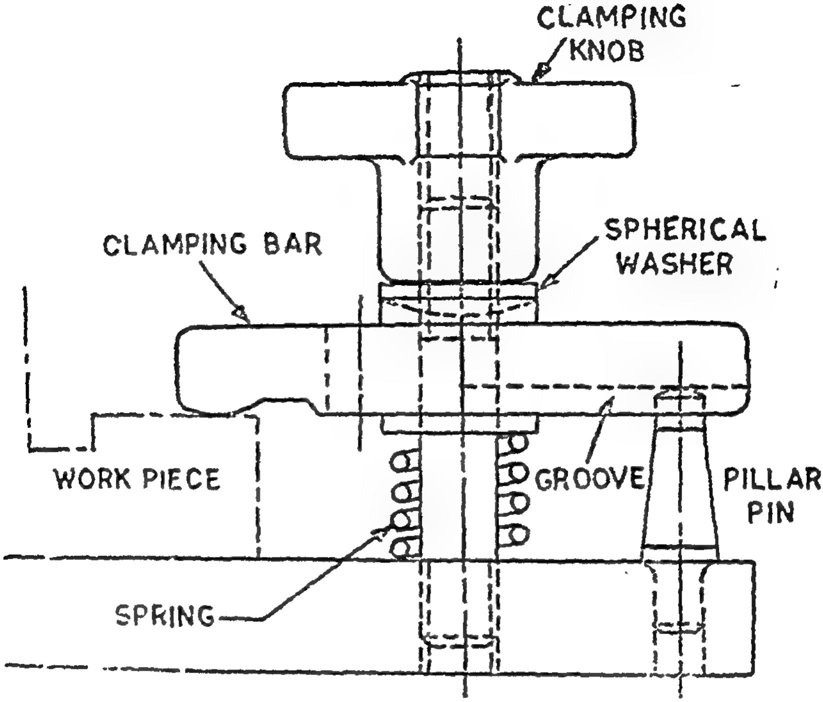


Fig. 14·26

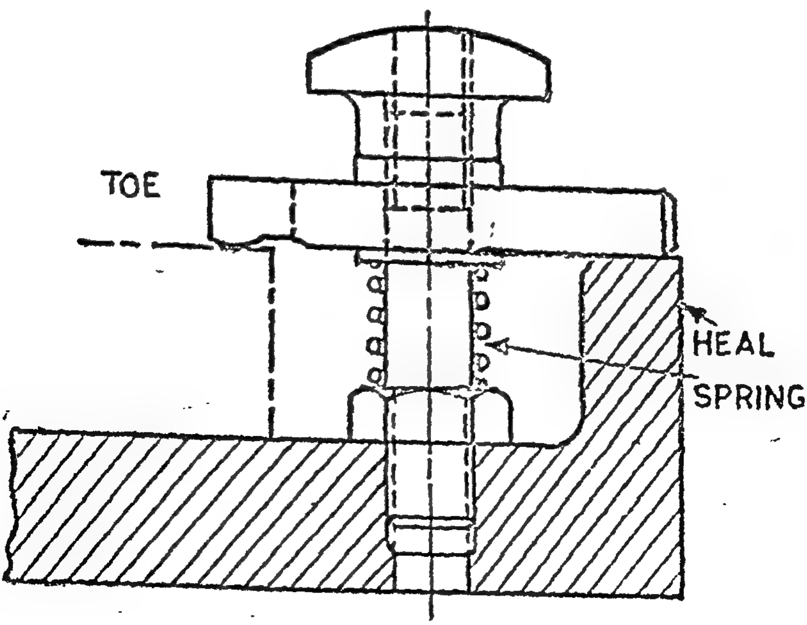


Fig. 14·27 (a)

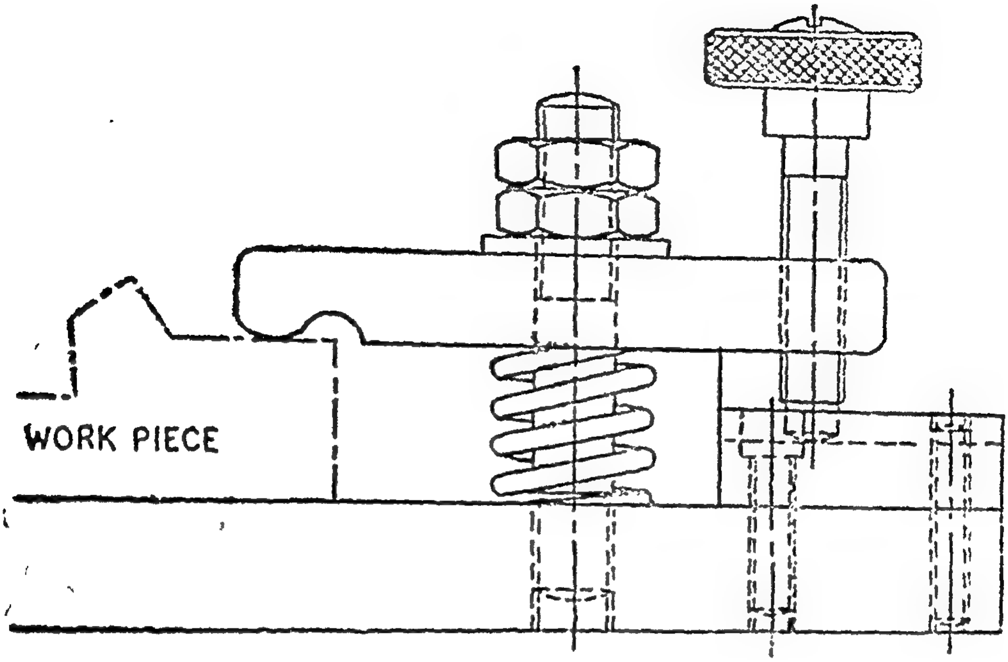


Fig. 14·27 (*b*)

If is bolt diameter ; W and S, the width and depth of clamp ; then *W* is approximately 3 *D* and *S* should not be less than *D*. Studs less than 12mm dia. are generally avoided. The strap clamps work on the lever principle. In the first three the force is applied in the middle by turning the nut with the help of a spanner. The heel acts as the fulcrum and the contact point bears the reaction. In the 4th type show the middle portions acts as fulcrum. Force *P* is applied by moving the heel up with the help of a spanner. Force exerted by strap is the reaction *R*.

Spherical washers used under the nuts of the strap clamps, offer the following advantages, 1. Maximum area is in contact with bar even when the bar is tilted at an angle. 2. Since spherical washers are hardened and ground they are less likely to wear.

2. Screw Clamps :

In the strap clamps it is the nut or the heel that is moved and the force to be exerted by this is obtained by a leverage action where as in the screw clamp the screw which is moved towards work piece

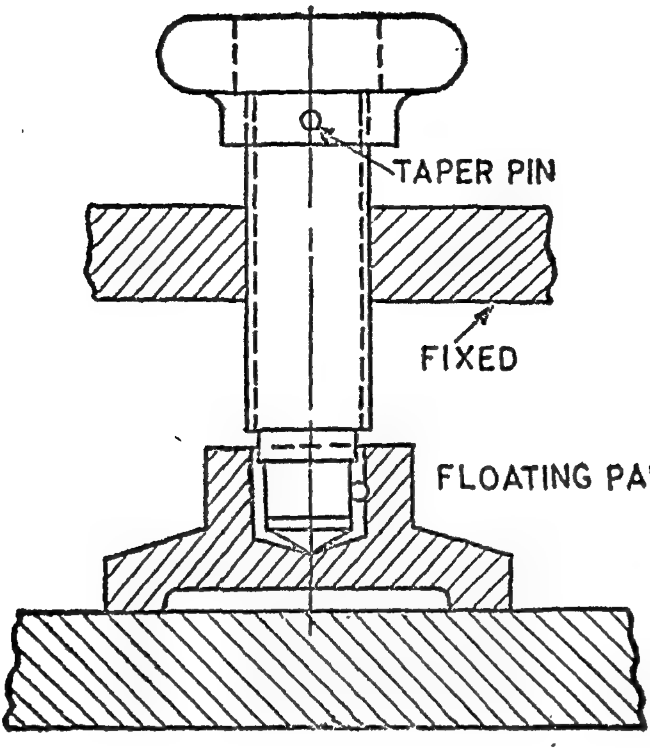


Fig 14.28

directly exerts pressure on the workpiece. It is provided with a floating pad at its end to reduce the danger of workpiece displacement and of denting the clampe surface, as well as to reduce deflections of the screw where it acts on a surface not square with its axis. The force exerted by a screw clamp of the type shown in fig. 14·28 is determined from the formula :—

$$P_c = \frac{PL}{r_f \quad (\alpha+\phi)+0{\cdot}33\mu \dfrac{D^3-d^3}{D^2-d^2}}$$

Where P is the force applied on the wrench or handle in Kg.
L is the length of the wrench or handle in m. m.
r_f is the pitch radius of the thread in degrees.
α is the helix angle of the thread in degrees.
ϕ is the angle of friction of the thread.
μ is the coefficient of friction on the face of swivel pad.

A few methods of retaining floating pads on the end of the screw are illustrated in the figure 14·29 *a*, *b*, *c*. A floating pad can be

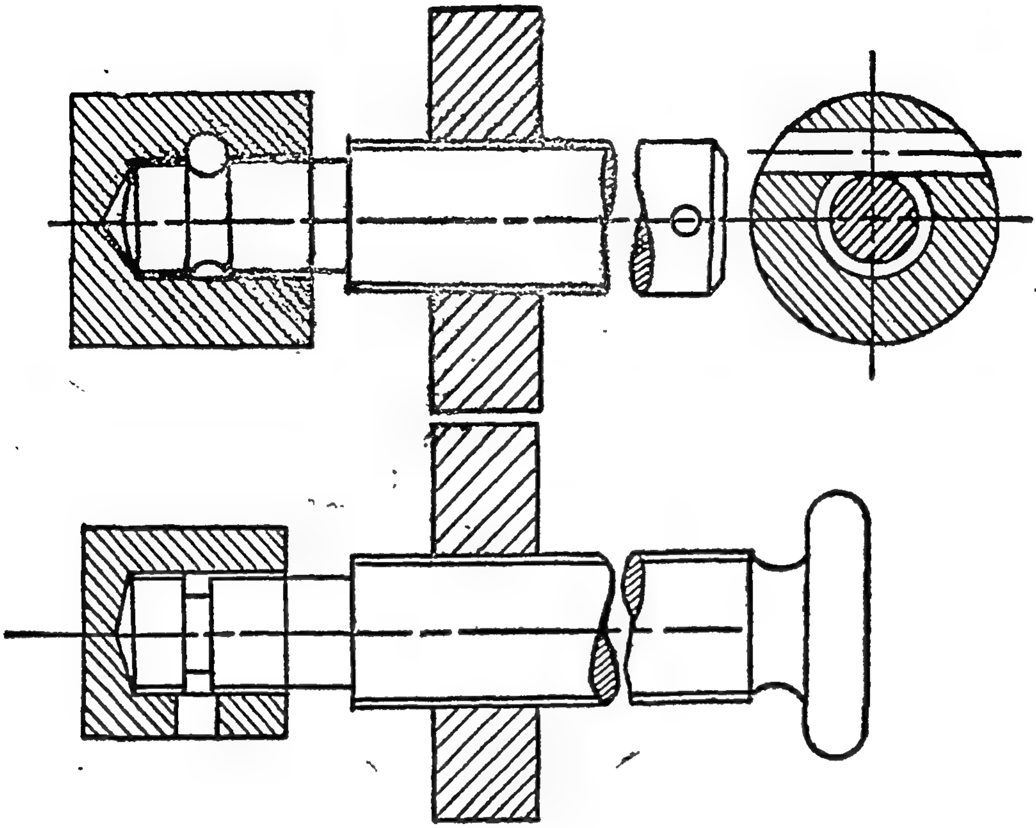


Fig. 14·29 (*a*, *b*)

retained with the help of a pin, screw or bolt and socket joint. Care should be taken that no load comes on the pin or screw.

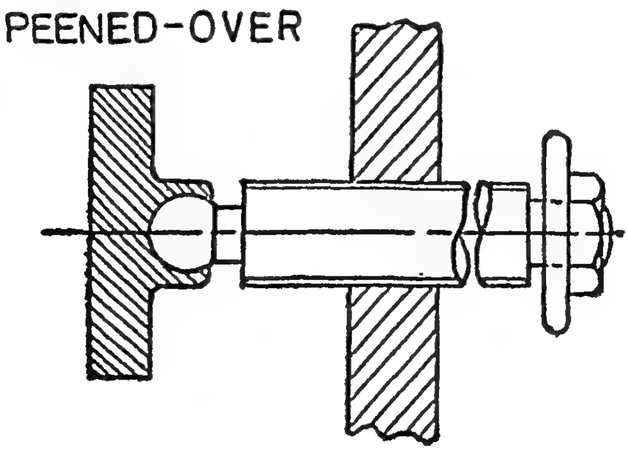


Fig. 7.29(*c*)

Screw clamps are the simplest and most versatile type of clamping elements. They possess the following defects however:

1. Work piece may be moved by the frictional force at the end of the screw if no floating pad is used.
2. Comparatively large time is required for clamping, especially if several screw clamps are to hold the work on different sides,
3. Comparatively large effort is required for their operation, causing fatigue to the worker.
4. Clamping force is not constant.

3. Hinged Clamps :

In some jigs it is required to lift the upper plate of the jig entirely to load and unload the component. This upper plate may contain jig bushes also. So the upper plate is hinged on one side to move it up and down and when this upper plate is closed a floating pad attached to the bottom side of the plate forces on the component or work piece. Now the hinged plate or lid is secured to the body of the jig in three ways : (*a*) by a latch (*b*) by a hook and (*c*) by a central clamping screw.

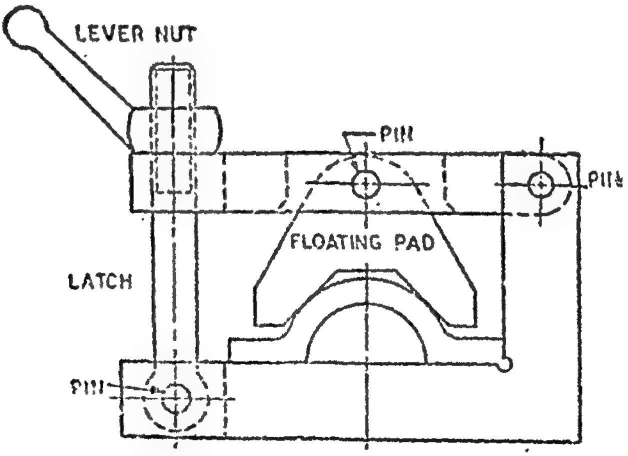


Fig. 14.30 (*a*)

Latch consists of an eye bolt hinged to the body on the eye hole and on the other hand there are threads. When the hinged lid is in position the latch is moved into position into a slot provided

in the hinged lid and nut is tightened on the lid. This nut may be level nut for convenience. (fig. 14.30a.)

In the hook type arrangement, a hook cam is fitted to the latch instead of lever nut for clamping the hinged lid. This arrangement permits the job to be handled faster (fig 14.30b)

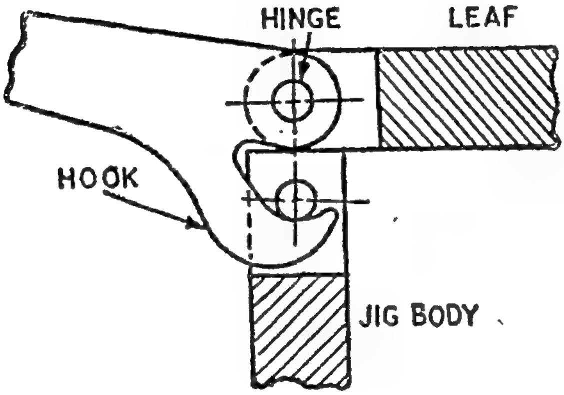


Fig. 14·30b

Hinged lid instead of being moved up and down, some times, can be moved side ways also and it can be tightened in position with the help of a thumb screw and two shoulder screws. Such a hidged lid is generally not used to carry the bush because the hinge provided by one of the shoulder screws is not accurate. Such clamps are sometimes called button clamps also. (fig. 14.30c.)

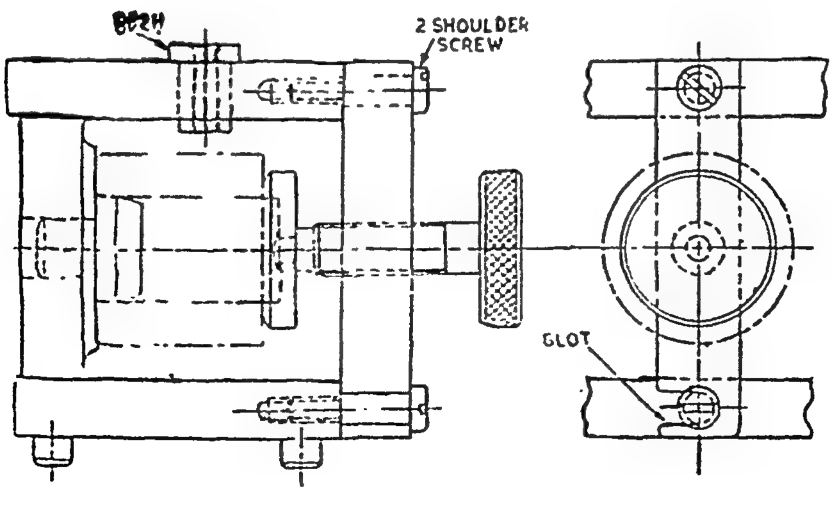


Fig. 14·30 c

4. C. Clamps :—

They are of two types (i) Free and (ii) captive C clamps (fig. 14.31 a, b.) They are very useful devices. The essential feature

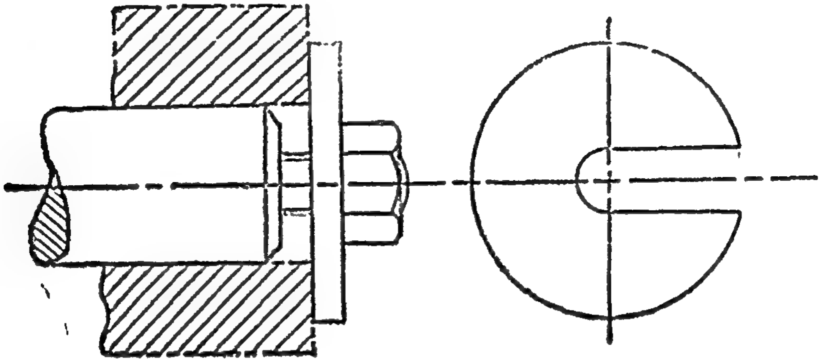


Fig. 14.31*a* C Clamp (free)

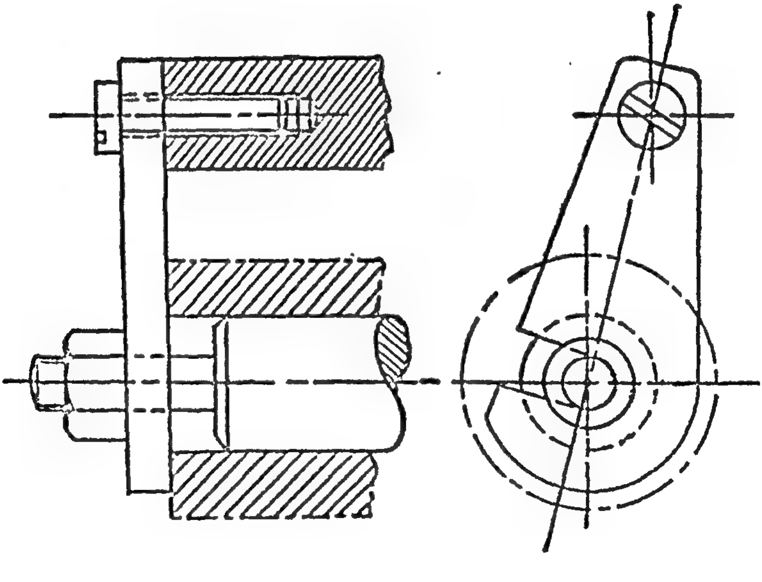


Fig. 14.31*b* C Clamp (Captive)

in both cases is that once the clamp has been removed or swung away the component can pass freely over the nut. The locking nut requires about one turn to release or lock the clamp and is therefore

quick acting. The plain washer is also chained to the body of the jig or fixture so that it may not be lost or worker may not search for it every time. The captive clamp washer is swung out of position on a hinge and is therefore a part of the jig body. (fig. 14.31*b*)

5. Wedge Clamps :

The plain wedge clamp is crude type of clamp used in places where accuracy is not very important. Wedge clamps are very much used for clamping long angle bars in twos on frames provided for the purpose. All sheets and angles used in wagon manufacturing are elamped to the frames by wedges only. The method works satisfactorily for the type of work involved. A simple component clamped with a wedge is shown in the figure 14.32. A wedge clamp has generally the following defects :—

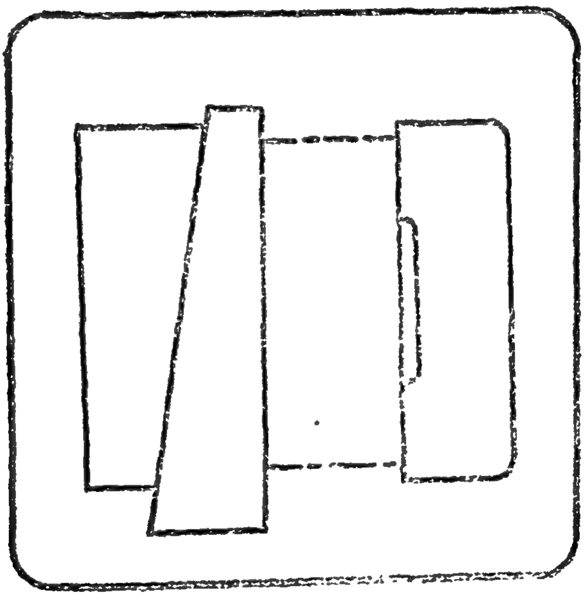


Fig. 14.32

1. To prevent accidental loosening after clamping the work piece the wedge angle should be very small (less than angle of friction.) The length of the wedge will thus be considerable for a small wedge angle even for small variations in the height of the work piece, since, the mean value of tan wedge angle for self locking should be about 0.1.

2. The work piece may be displaced in the jig or fixture when the wedge is moved for clamping.

3. At small wedge angle, excessive clamping force P may be obtained, for tan α=0.1 the force P is 10 times the force applied to the wedge. (fig. 14.32).

6. **Quick Acting Nut** :—A simple but effective time saving device is a nut with interrupted threads. The nut which must be specially made so that it is from two to three thread diameter in length has the hole slightly larger than the outside diameter of the thread on a stud. This clearance hole is machined at an angle between three and seven degrees. When the nut is assembled, it is Inclined to the clearance hole axis and passed over the male thread. When a positive end face has been found by the nut it is dropped on to the screw threads and is then tightly locked in about half a turn. (fig. 14.33.)

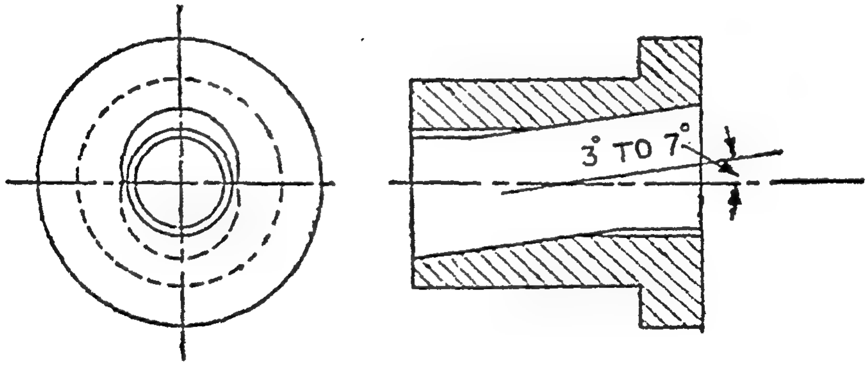


Fig. 14.33

7. **Toggle clamps** :—Toggle clamps depend for their action on the movements of rigid links ; figure 14.34 shows a simple toggle

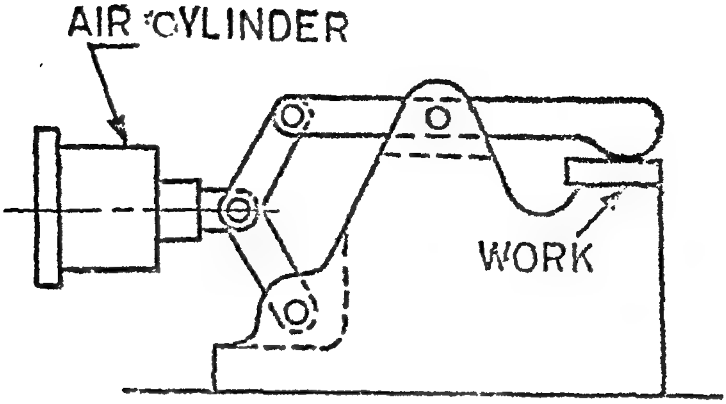


Fig. 14.34

clamp which illustrates the principle involed. The work piece is held securely under the clamping pad which move downward by forward motion of the piston in an air cylinder. Both clamping arm and cylinder are hinged to the body which may be a part of the jig body or mao be separately bolted to the jig body. Standard toggle joints developed by several companies are bolted to the fixtures wherever required. These have been used extensively lo hold sheet metal parts in position while they are being welded or otherwise fastened, The mechanical advantage of a toggle joint can be made very large with a compact mechanism.

Most of the clamps described so far incorporate a nut and screw assembly. The clamp holds the work piece when the nut or the screw is moved with the help of a spanner. Such devices are slow acting devices. However there are other types of clamps which can be termed as quick acting clamps. They are :—

1. Cam operated clamps.

2. Bayonut type-clamps.

They are in most cases more expensive to produce and maintain. This additional cost however is more than offset by a corresponding reduction in operating time. Cam of the cam operated clamp can be utilised in several ways.

8. Quick acting Cam operated clamps :—There are two

main types of cam clamps (*I*) direct acting levers and (*II*) shaft eccentrics. The hook lever of the hinged clamp discussed earlier, also employs a cam action. There are two further variations of the direct acting lever cam clamps. In one case Fig. 14.35*a* the handle is at the centre of the strap and the cam has replaced the nut of the strap clamp and has thus eliminated slow movement of the nut. In the other case (fig. 14.35*b*) the cam serves the purpose of adjustable heel of the strap clamp is and clamp called a cam actuated strap calmp.

The shaft eccentric cam clamp is used for universal jig construction. This type of clamping allows high presure to be exerted

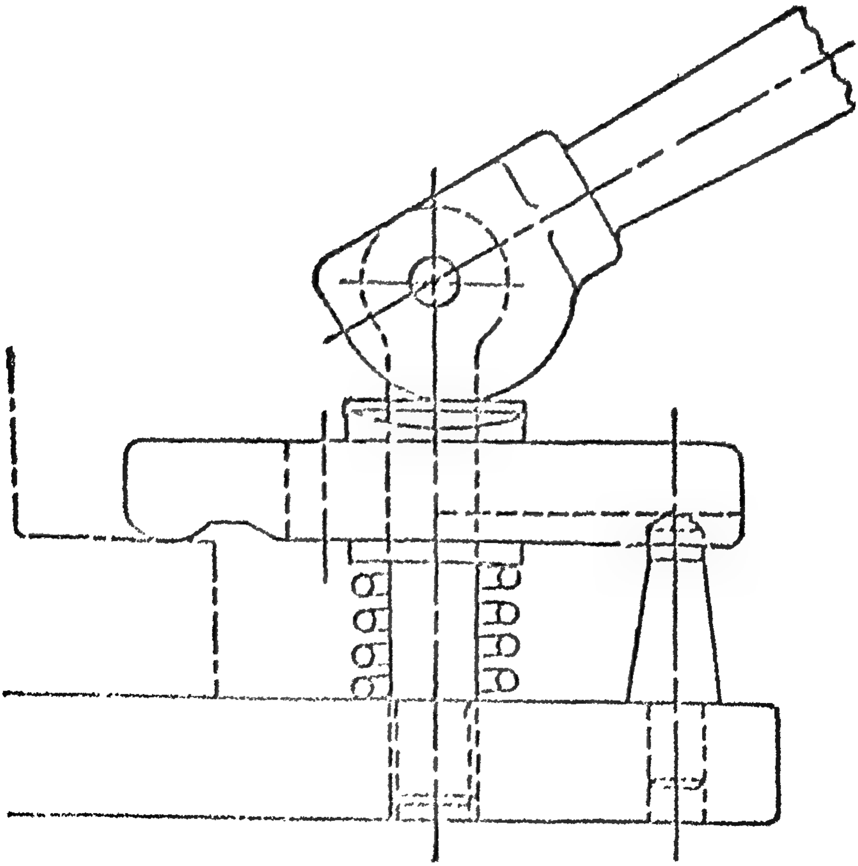


Fig. 14.35*a*

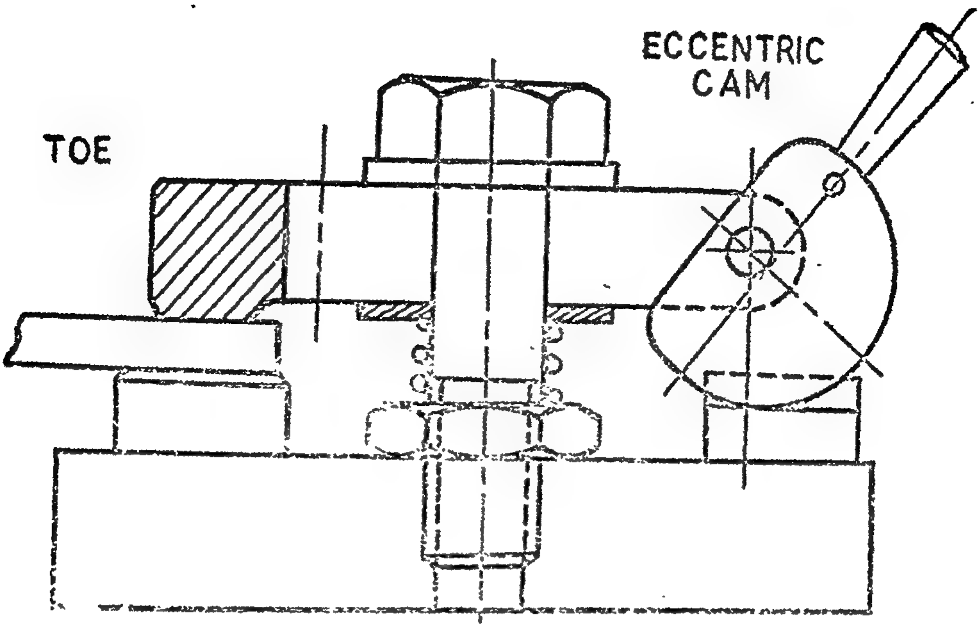


Fig. 14.35*b*

and also affords an adequate range or linear movement. Fig 14.36 shows the outline of a jig with an eccentric clamp.

Cam Contours :

Cam contours may be eccentric or spiral. Eccentric cams though simple to manufacture do not lock properly and get loosened by vibrations. For an eccentric cam to stay locked after clamping the work piece, the ratio of its diameter D to its eccentricity E should be maintained between 14 to 16 while designing the cam. This ratio $\frac{D}{E}$ is called characteristics of the cam.

Fig. 14.37 shows a direct acting lever cam of the eccentric type. The radius of the circle is r with centre at C. Lever is pivoted at P with a pin. E is thus the eccentricity of the cam. When the handle is rotated in a clockwise direction centre C will travel in circle A until the circumference contacts work piece at B. Through the normal force exerted at B will be considerable due to leverage L but equal and opposite normal reactions F will always create a counter acting

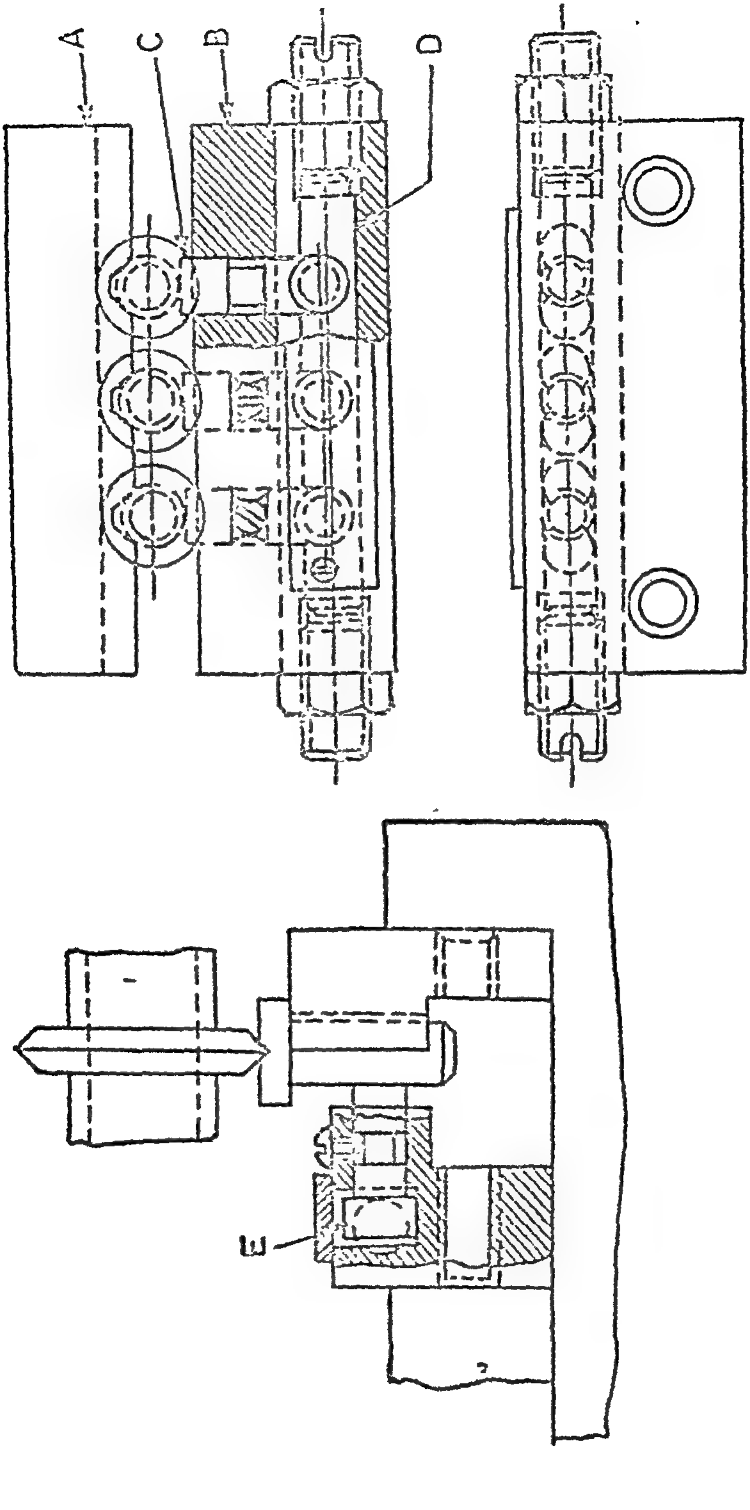


Fig. 14·36

torque and make the action of the cam uncertain. Such an awk-

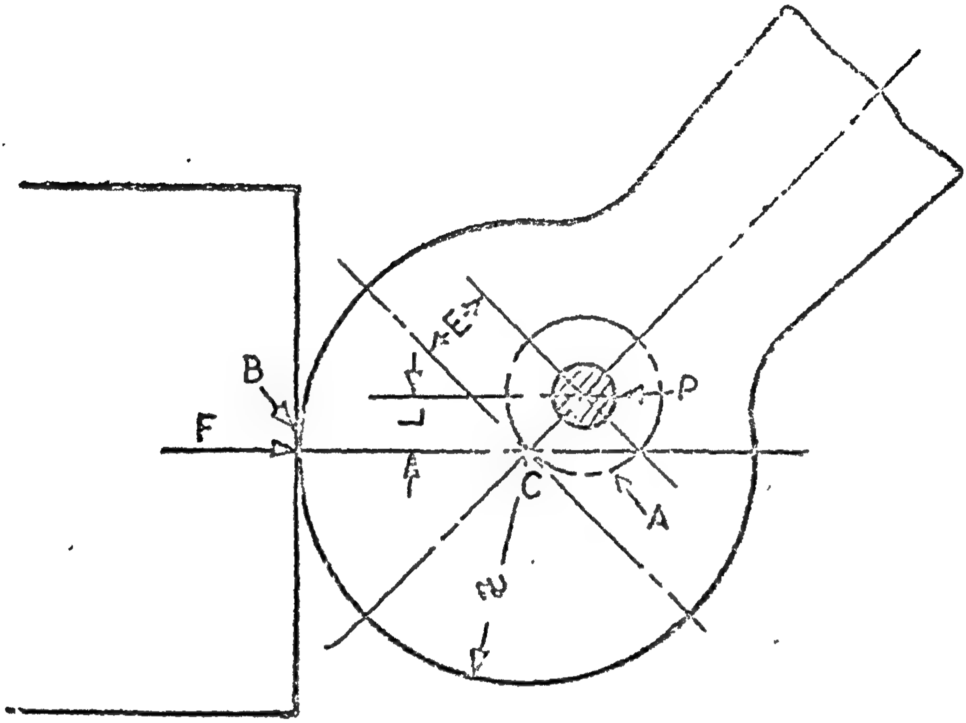


Fig. 14.37

ward position is avoided in the spiral cam where the normal reaction passes through the pivot point.

Layout of Spiral Cam :

For a spiral cam to be designed rise of the cam and the throw of cam is decided first. Rise is the distance required for locking action and throw indicates the degrees by which the handle should be rotated to obtain the desired rise. The throw of a cam is about 90° but 10° degree are added on each end as a precaution against inaccurate assembly. Total throw therefore is 110°. A rite of ·001 inch for every degree of arc at a radius of one inch can also be conveniently used. Thus, rise for 110° degree throw at a radius of 2" will be $110 \times 2 \times .001 = .22$ inch. Too rapid a rise makes the locking inconvenient for the operator and also the cam structure becomes larger

or clumsy. With too small a rise, trouble will be experienced with work pieces that vary in size.

Draw the concentric circles between which the spiral cam is to be laid fig. 14·38. The centre of the circles is exactly in a line normal to the desired point of contact with the work piece. The difference between radius of two circles is the rise ·05 of the cam. Draw the line normal to the workpiece passing through the centre of the circles. Layout 55° above this line and 55° below this line. Draw radial lines at the extremes. Draw the radial lines through each division as shown. Divide ·05 into the same number of parts. Number each part as shown draw the arc from each numbered part 05 to meet

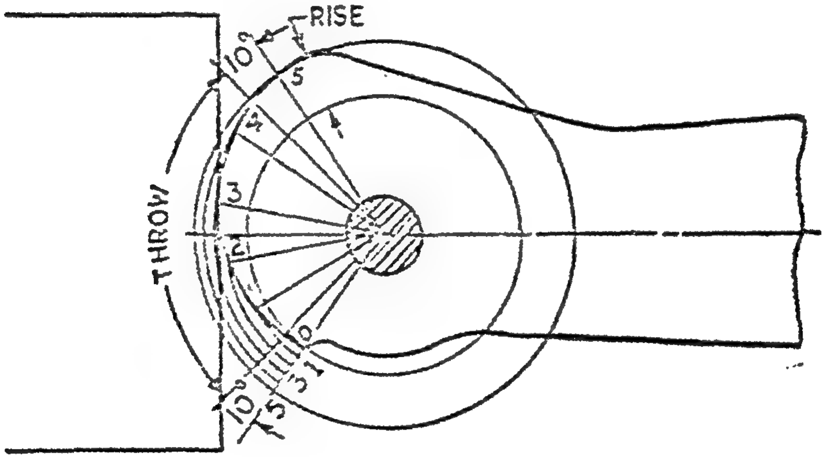


Fig. 14·38

its corresponding number on a radial line, thus establishing points through which a smooth curve can be drawn to form a true spiral for the working face of the cam.

Bayonet type quick acting clamps :

A simple thread with one turn or part of a turn is cut in the plunger together with a slot parallel with the centre line. A pin engages in this in such a manner as to allow the plunger to slide freely with rapid movement like that of a bayonet when the pin is in the groove and to give a powerful thrust to the plunger when it is twisted

with the pin in the thread like an ordinary screw in its nut. In this manner the work piece can be released with a partial turn of the knob and the plunger quickly pulled clear for reloading. Both the plunger and pin should be made of steel, hardened and ground for long service.

Multiple Clamps :

These clamps either clamp a work piece at several places simultaneously or clamp several work places at the same time. The multiple clamps use the principle of the hinged clamp but instead of one clamping pad pivoted to the lid they contain several in a certain order depending upon the number of pieces to be clamped. Locking in multiple clamping is also accomplished by latches. Force applied at one point is transmitted by the pivoted pads to the several clamping points. Multiple clamps are designed to clamp a number of work pieces which differ from each other to some extent in form and size. Provision is always made for equalising the clamping forces within the device themselves. Such clamps are therefore, called equilisers also. Equilisers should not be confused with centralisers discussed under location principles. (fig. 14.38 *a*)

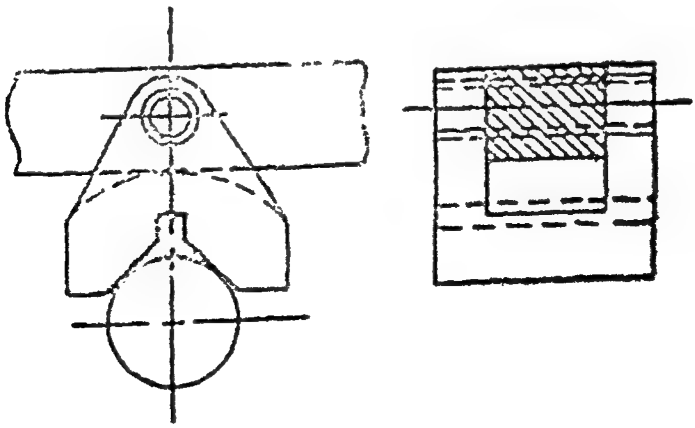


Fig. 14·38*a*

Drilling Jigs

Elements of a jig :

A jig may consists of the following essential components :

1. Body.
2. Locating elements,
3. Clamping elements.
4. Tool guiding element or the jig bush.

However as the jig becomes costly its usefulness also increases because some other elements may also be added to it. Some of the other elements which can be provided on costly jigs are :

5. Indexing devices.
6. Power devices for operating clamping elements.
7. Jig feet for easy movement if the jig is to be frequently moved.
8. Fastening parts if the jig is not to be moved from one location below the machine.

Jig body, box or the frame is the most important component to which all other components are either push fitted or screwed or welded. Depending upon the method by which the body skeleton is prepared and the elements are added the jig bodies are classified as built up jigs, welded or fabricated jigs or cast iron jigs. Fabrication of jigs is becoming very popular these days. It is the cheapest way of making a jig. However there is one disadvantage ; all jigs fabricated by welding must be heat treated to relieve the stress set up during welding operations. If the welded jig is not heat treated it may loose its accuracy as the stresses relieve themselves during vibration.

JIG BUSHES

The parts of a drill jig through which the cutting tools such as drills, core drills, reamers or boring bars are operated and located are called jig bushes. The jig bush dimensions have been standardised now so that they may be available commercially. Jig bushes are made of mild steel but are always case hardened before use. Jig bushes even though they are hardened become unserviceable due to wear after some use. Most of the wear is due to the action of the chip and the rate of wear depends largely on the material being drilled. Consideration should be given to the necessity of replacing

the bushings when the jig is designed. Drill bushes may be classified as follows :—

1. Fixed bushes (plain or headed) (fig 14·39)
2. Liner bushes (fig 14·40).
3. Renewable bushes (fig. 14·41).
4. Slip bushes. (fig. 14·42).
5. Screw or clamp bushes. (fig. 14·43).
6. Special bushes. (fig. 14·43a).

1. Fixed bushes :—They are pressed permanently into position and when wornout cannot be readily replaced. They are used when a hole is produced by one tool only. There are two types of this bush. Plain and headed.

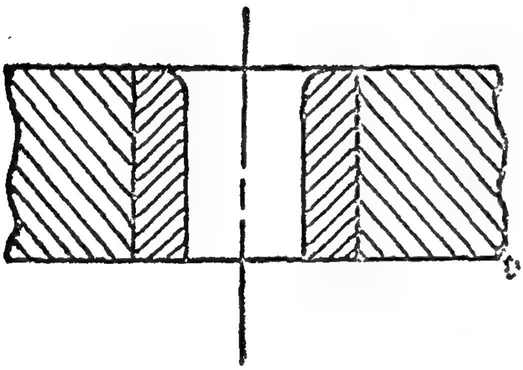


Fig. 14·39*a*

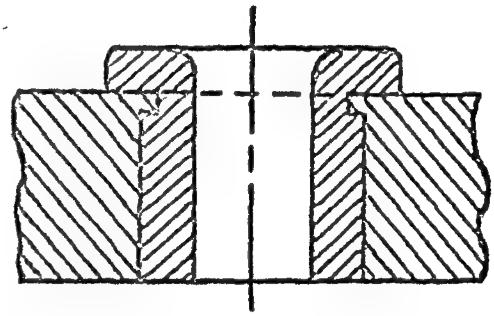


Fig. 14·39*b*

The plain bushes have four advantages (*i*) First cost is slightly lower. (*i*) They can be set closer together. (3) They are less likely to interfere with parts of the drill press. (4) They can be used on all six sides of a box type jig and still the jig will sit flush on the drill press table. However, there is one disadvantage also. The plain bushings are liable to work through the jig plate either bythe pressure of the drill itself or because of blows from the drilling machine spindle. Therefore the headed bushes are commonly used.

While making drawings of the jig bushes and subsequently manufacturing them a few constitutional features of bushing should be well remembered.

1. An adequate chamfer should be provided at the top of the bore for easy entrance of drills or reamers.
2. An adequate chamfer should be provided at the bottom of their external diameters.
3. Neck of the headed bush should be provided a under cut so that it sit flush on the jig plate.
4. Edges of head diameter should also be chamfered to remove sharpness.

2. Liner Bushes :

Liner bushes are also press fitted like the fixed bushes but their main purpose is different. The liner bush is used to act as a hardened guide for both renewable and slip bushes. However, it can be used for guiding the tool usually the largest in any combination.

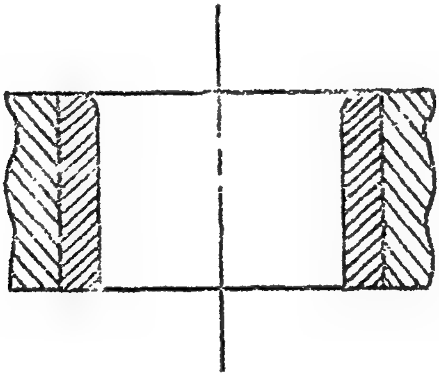


Fig. 14·40

3. Renewable bushes :

These are special types of fixed bushes. When they require to be replaced due to wear, a retaining screw is removed and the worn-bush is taken out. A new bush is then easily substituted. Where

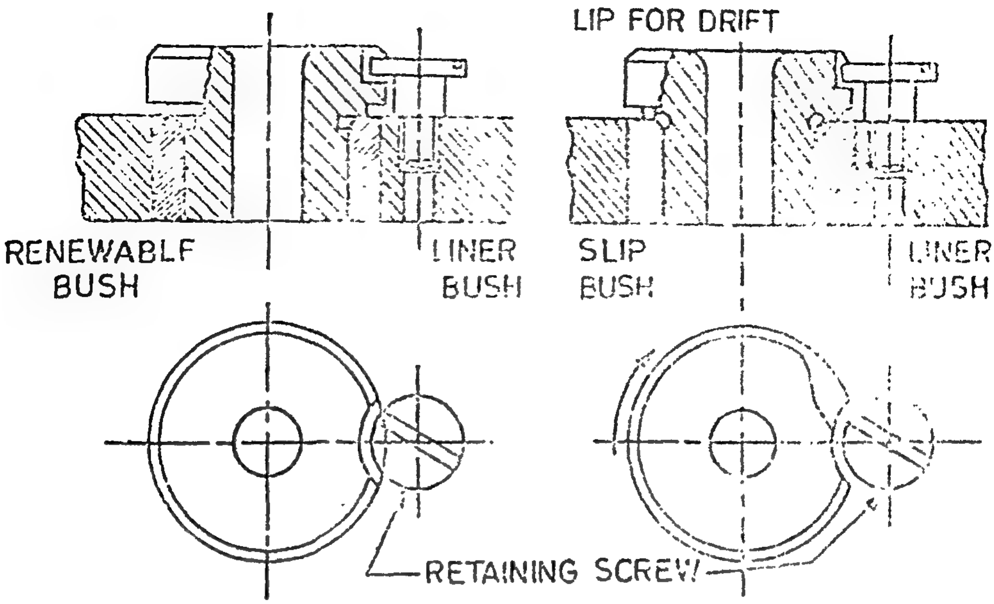


Fig. 14·41 & 14·42

as the removal of a fixed bush when wornout is a great problem. It requires hammering the bush out. Renewable bushes are slipped over the inner bushes for easy removal.

4. **Slip Bushes :**

When a hole is to be drilled in stages and then reamed also it is the best practice to use slip bushes rather than use separate jigs for each operation. Here again the liner bush in which the slip bushes are placed, is also utilised for the last operation. Slip bushes are made in such a way that there is no need to open the retaining screw. The time of slipping a bush is considerably minimised by properly designing the head of the bush. For taking the bush out the head is given a back turn and the bush is free of the retaining screw and can be easily taken out.

5. **Screw or Clamping Bushes :**

The screw bushes are provided with threads on their outside diameters. For some type of light work where a metal is to be drilled the screw bush is used to clamp the work piece below and also to guide the tool. It then becomes a simple and in expansive clamping device of the jig but eccentricity between the thread of tl

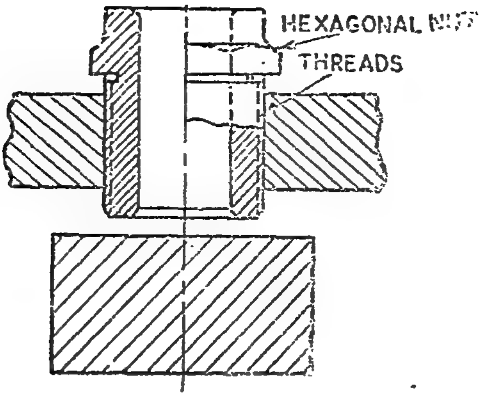


Fig. 14·43*a*

bushing and the thread in the jig plate may result in holes being drilled off centre. Again rapid wear of the threads in the plate will cause inaccuracy in the exact location of the hole to be drilled. Due to these reasons screw bushes are also not preferred for accurate work.

6. **Special bushes :**

While standard bushings should always be used wherever possible, it is sometimes necessary to design a special bushing. A typical

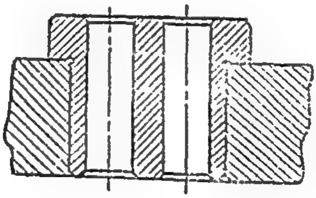


Fig. 14·43*b*

case occurs when two holes are close-together and heads and walls of two standard bushes would interfere with each other. A special bush with two holes can be designed to meet these conditions.

TYPES OF DRILLING JIGS

It should be borne in mind that widely varying types of jigs could be made for a given component, each of which would be satisfactory for producing the piece, but some would be more effi-

cient than others and again they would vary considerably in the cost of manufacture. An attempt has been made here to classify the drilling jigs broadly so that the designer may draw an idea to start with and improve the design, himself. There can not be drawn a strict line of demarcation while classifying the jigs.

1. Template Jig : Template jig is a of very simple type jig which can be held over the component by hand while drilling small diameter holes As the jig is just positioned by the operator and does not contain locating points, it is used where accuracy of holes relative to each other is important and variations in position of the holes relative to work piece can be tolerated. Such a template may or may not contain hardened bushes to guide the drill. However, templates are sometimes used for making off the holes to be drilled. The component and

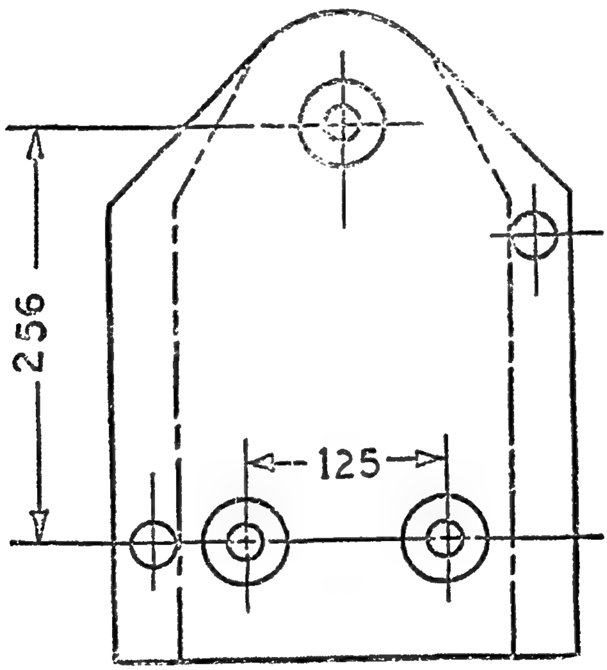


Fig. 14.44

template are rested on a block while centre pops are made through the counter sunk holes in the template. The template is then removed and the component is set up for drilling to the centre pops. This methods is not very accurate but it saves the cost of marking.

Fig. 14·44 shows a bracket with three holes. The two holes are used to fit it to the frame and third in the circular portion is to serve as fulcrum for lever of the brake drum. Relative position of the holes has been dimensioned and outer periphery is of no importance. The template jig for such a part is shown. The two pins diagonally opposite will locate the component and will not allow the template to rotate. The template is held on the component with manual pressure. The cylindrical portion of the big bushes should be less than the thickness of the jig plate so that jig plate is fully in contact with component.

2. **Plate Jigs :** The main part of such a jig is the plate from which it takes its name. Other essential parts are the drill bushings and locating pins. A clamping device is needed, but for some jigs this is not included in the jig proper and may consist of a C clamp or a machinists set of clamps. Plate jig becomes necessary where the whole pattern to be drilled, has a definite relation to the periphery of the component. Where as in the template jigs the pins were to restrict the movement of the template, here pins are used to locate the plate jig from the periphery and thus achieve exact relationship of the hole and periphery. Fig. 14·45 shows the component to be drilled. The centre line of the three holes from the periphery is important. Further the holes in other directions are exactly in the centre line. Tolerances have been mentioned for both the dimensions. The plate jig designed for this component has six locating pins and on one side clamping screws are also provided. Such a plate jig can drill several components stacked on each other. Apart from the two clamping screws which must have floating pads to bear upon the plate sides, some clamping from above will also become necessary in that case.

Plate jigs are very common for drilling holes in long strips or angles. Several strips are stacked and plate jig is positioned above them locating it by pins on mutually perpendicular sides. The claming element is separate from the jig.

3. **Channel Jigs :** In this type the work piece is placed in a channel shaped trough and clamped by means of a screw. This

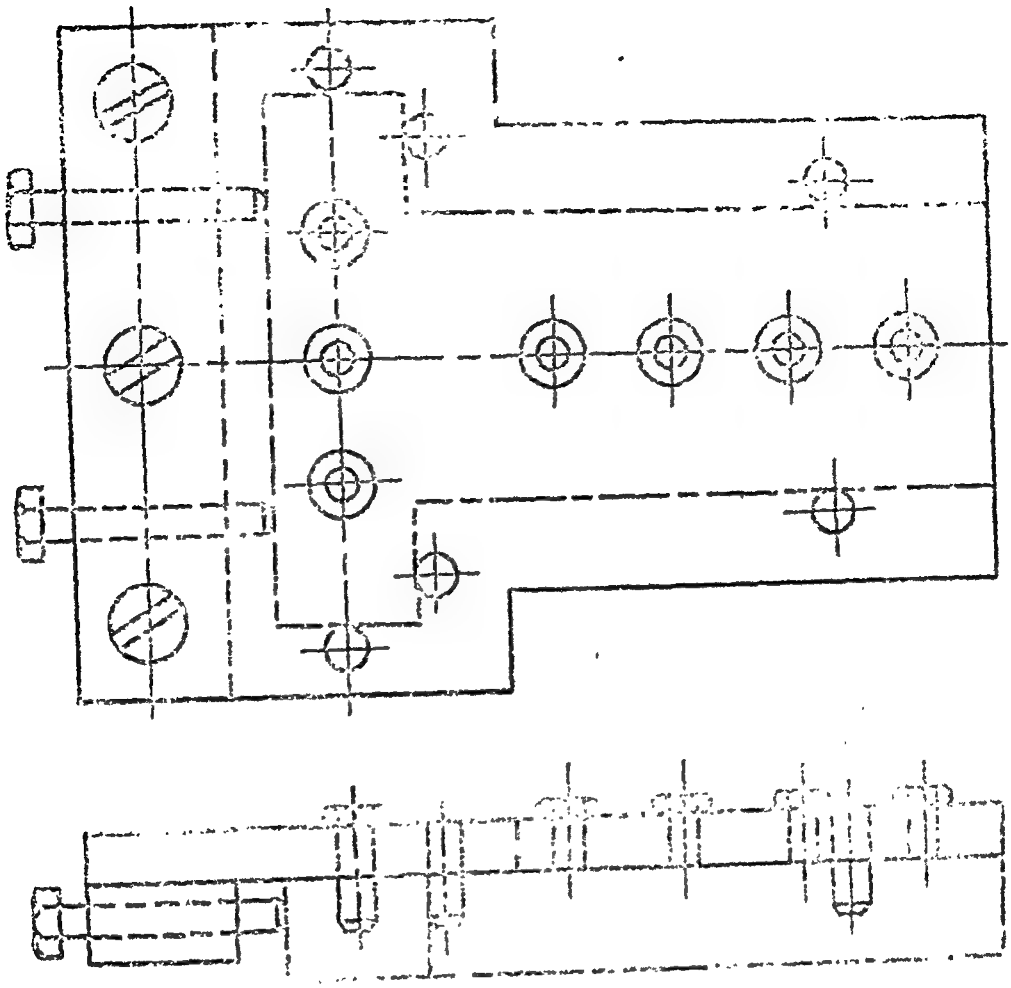


Fig. 14·45

type is limited to jobs having workpieces of a simple symmetrical shape. A channel can accommodate two angles also in its corners. Clamping is included in the centre line of the channel at several places. The drilling machine for drilling over a length of six to seven feet of angles held in a channel jig must move its rails along the length of the channel. Such drilling machines are commonly used in a wagon manufacturing concern where long angles, channels, plates and strips used in wagon construction are to be processed.

4. **Leaf Jigs** : A leaf jig is generally a small jig incorpporating a hinged leaf carrying the bushings and through which clamping pressure is applied. The leaf is held on to the jig body with the help of a eye bolt where the eye is hinged to the body with a pin and a nut on the threaded portion of the bolt tightens on the leaf.

clamping of the leaf jig can be accomplished with the help of a cam. Leaf jigs are also called latch jigs. Most leaf jigs are easy to load and their normally open design allows rapid and easy removal of chips and good visibility of the work piece.

The clamping pressure on the work piece should not be applied directly by the leaf part of the jig but through a thumb screw in the leaf. The thumb screw should further have a floating pad to adjust on an uneven surface. If the leaf is used directly for clamping, the axis of the bushes will not remain vertical if the two faces *X* & *Y* are not parallel fig. 14·46 & fig. 14·47.

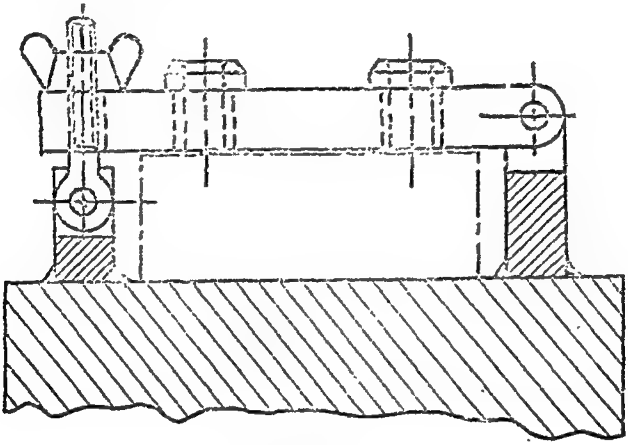


Fig. 14·46

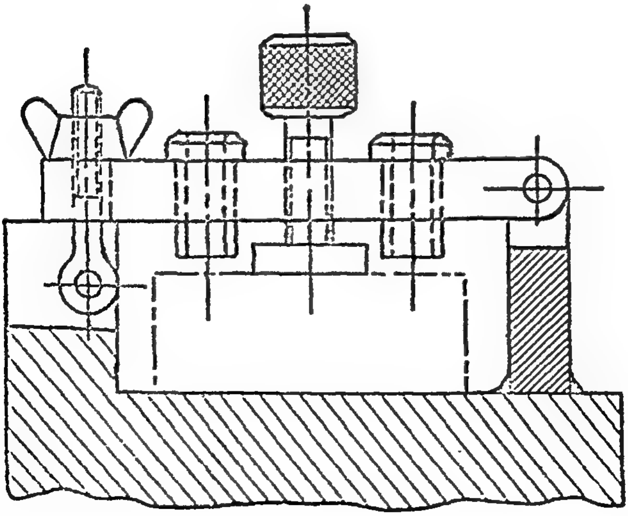


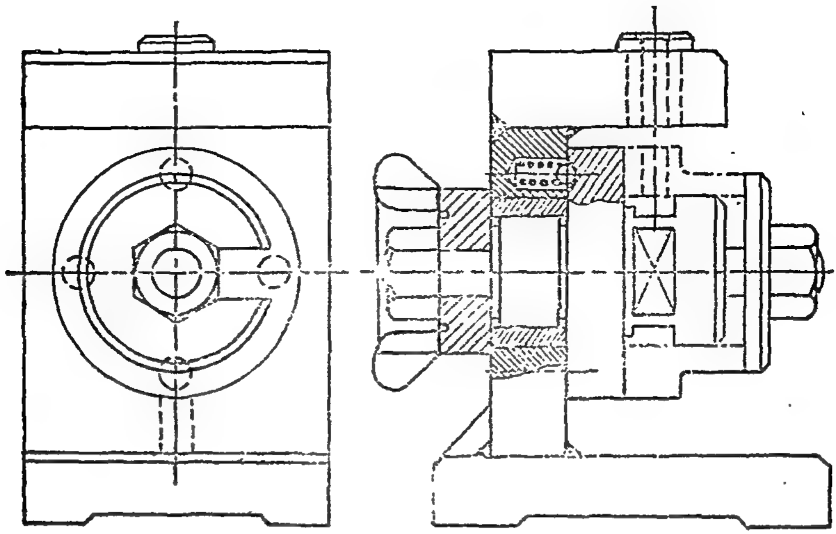
Fig. 14·47

5. **Box and tumble jigs :**— It looks like a closed box. It has drill bushes provided in two or more sides. Each side is brought up under the drill spindle by tumbling the jig. In this way all jigs of the box type, leaf type or channel type which have to be tumbled to present desired work face to drill spindle are called tumble jigs also. Feet are certainly needed, opposite to each bush plate in a box or rumble jig of headed bushes are used. One side of a box jig is generally open to insert the job and accommodate clamping system. A workpiece in a box jig should be located by 3-2-1 principle on supporting pins. Clamping screws placed opposite to 2 pins and 1 pin plane force the work piece in place. A clamping device opposite to 3 pins plane finally constrants all degrees of freedom.

6. **Pot-type Jigs :** Circular components which have both an external diameter and an internal diameter suitable for location purposes are drilled in pot type jigs. The jigs consists essentially of two parts. The body in the form of a pot carries the workpiece and workpiece carries the bush plate. The bush plate is also provided with locating spigots and can be used without the pot body also.

7. **Universal Jigs :** These jigs are produced as basic units by a few firms. By further additions they can be converted into useful jigs for purticular purposes. They have many advantages where the cost of adoptation is low and a large production merits their higher first cost. One jig can be used for many different workpieces by changing or moving the top plate, or bushing etc. If the top plate is movable with the help of a handle the jigs are sometimes called pump jigs also.

8. **Index Jigs :** Such jigs (fig. 14·48) are used to drill a series of holes in a circle on the face of a work piece. The work piece is indexed and the next place where the hole is to be drilled, comes under the jig bush. Indexing devices, to accomplish the indexing are discussed separately.



Fig, 14·48

9. **Built up Jigs and Welded Jigs :** All types of jigs mentioned so far can be made either by building up with the help of dowels and cap screws or by welding the plates, and angles etc. Depending upon the mode of construction jigs may be built up jigs or welded jigs.

10. **Trunion Jigs :** Heavy box jigs where holes are to be drilled in several faces are moved on trunions instead of the operater tumbling them for bringing the bush faces at the top. Therefore, a heavy jig moving on trunions is referred to as trunion jig. The jig proper carries trunions at its ends which rotate in cast bearing brackets, monuted on a long channel iron. Every time the jig is rotated it must be locked in such a way that the face in which the hole is to be drilled is absolutely horizontal. The pin and the locating hole for locking the jig should be wear resistant.

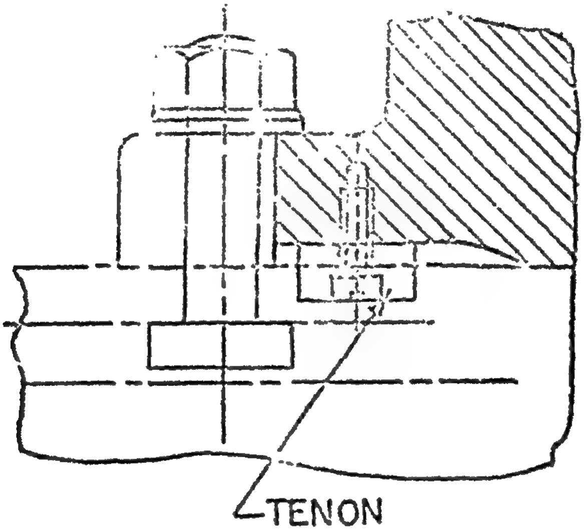
ELEMENTS OF A MILLING FIXTURE

A milling fixture essentially consists of the following components built up in to the main base.

1. **Base :** The base of a fixture is about 20 to 25mm thick, rigid enough not to deflect upward during upcut milling. It absorbs forces tending to set up vibrational effects of chatter. Cast iron acts as an absorbent more efficiently than does fabricated steel. Base

is provided with lugs on each side for fixing the base to the machine table. Lug surfaces are slightly raised up and spot faced.

2. Tenon strip : The position of the base on the table is accurately located by means of tenon strips. The tenons identical in width with the slot in the machine table are fixed below the base. The length of a tenon strip is twice the width. They are made of steel, ground and hardened. The tenon strip fixes the base to machine table in the same relative position every time. They are held to the base with the help of screws. (fig. 14·49).



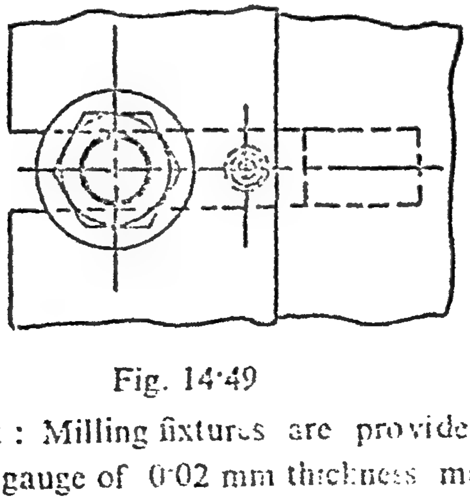
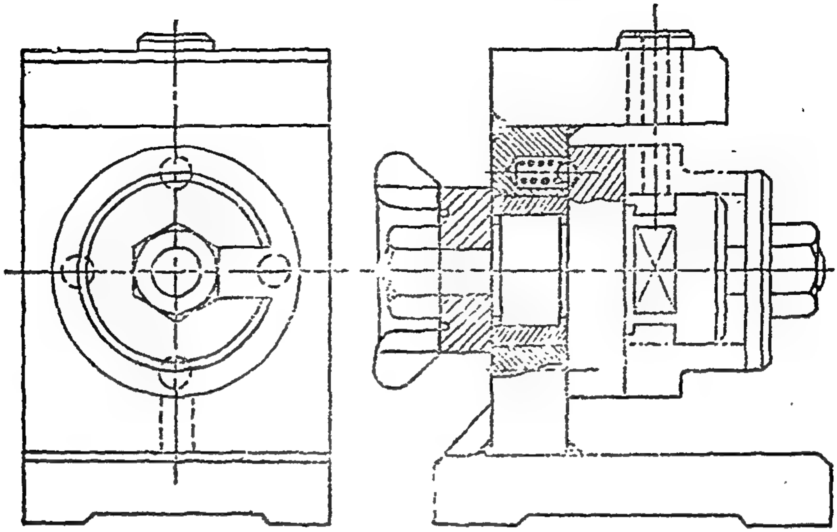


Fig. 14·49

3. Setting Block : Milling fixtures are provided with a setting block so that a feeler gauge of 0·02 mm thickness may be used for setting the fixture relative to the cutters. It is made of steel, duly hardened and ground. The setting piece is fixed to the base of fixture by means of screws and dowels. (fig. 14·50.)



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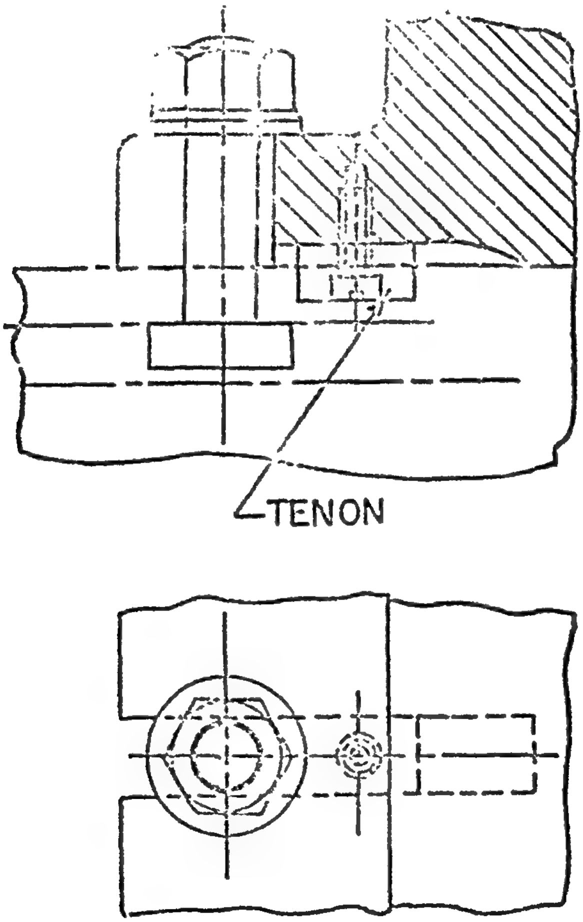

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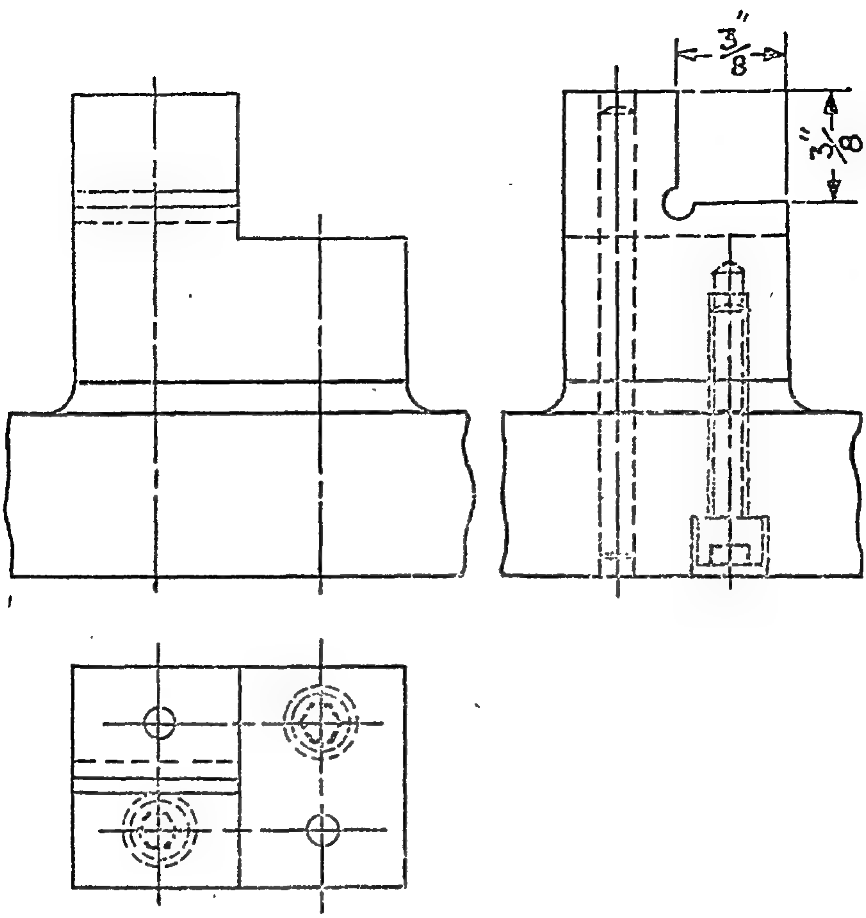

Fig. 14·50

4. Tee bolts : The fixture is bolted to the machine table with tee bolts suitable for the slots provided in the machine table. The shank of the bolt goes into the lug and nut is tightened on the screwed portion.

5. Clamping device : A fixture may have any one of the clamping devices mentioned earlier to clamp the workpieces.

6. Locating or positioning element : The excessive thrust of the cutter must be resisted by a fixed stop because clamping device only may not be sufficient.

CLASSIFICATIONS OF MILLING FIXTURES

Milling fixtures can be classified in several ways (1) Type of oparations performed on the work (2) Method of milling (3) Method of clamping the work pieces. According to type of operations the

fixtures may be classified as slotting, straddle milling, face milling or form milling fixtures. According to method of milling fixture may be named as a single piece milling fixture, string milling fixture, abreast milling fixture, reciprocal milling fixture, progressive milling fixture and index milling fixture. Third classification may identify the fixture as hand clamping fixture, power clamping fixture or automatic clamping fixture. However, important types of fixtures most commonly pronounced may belong to any of the above three classes. Important types of fixtures are :—

1. Special vise jaw fixtures.
2. Plain milling fixtures.
3. String milling fixtures.
4. Gang milling fixtures.
5. Profile milling fixtures.
6. Continuous rotary milling fixtures.
7. Indexing milling fixtures.

1. **Special vise jaws** : A commonly used work holding device for milling is the plain or universal vise. Provision is made for attaching special jaw inserts to the fixed and movable vise jaws. Expenditure on special milling fixtures can often be avoided by carefully through out special vice jaws, so formed as to provide location and clamping for either one or a series of operations on a component.

3. **Plain milling fixtures** : These fixtures are specially designed for components which are complicated in shape and require special adjustment of the jack screws or shaping loaded rest pins individually for each component. These milling fixtures therefore hold only one component because each component requires special attention. It is particularly true when first operation is performed on a forging or casting. The milled surface is to serve a datum for all other dimensions in subsequent operations. Therefore, the first surface to be machined is carefully set up and milling fixture is specially designed for a single component, incorporating jack screws etc. The first operation in milling fixtures requires great skill on the part of the designer.

String or line milling fixtures : As the name suggests, this type occupies a considerable length of machine table and holds a number of components in a line or in tandem. The length of the

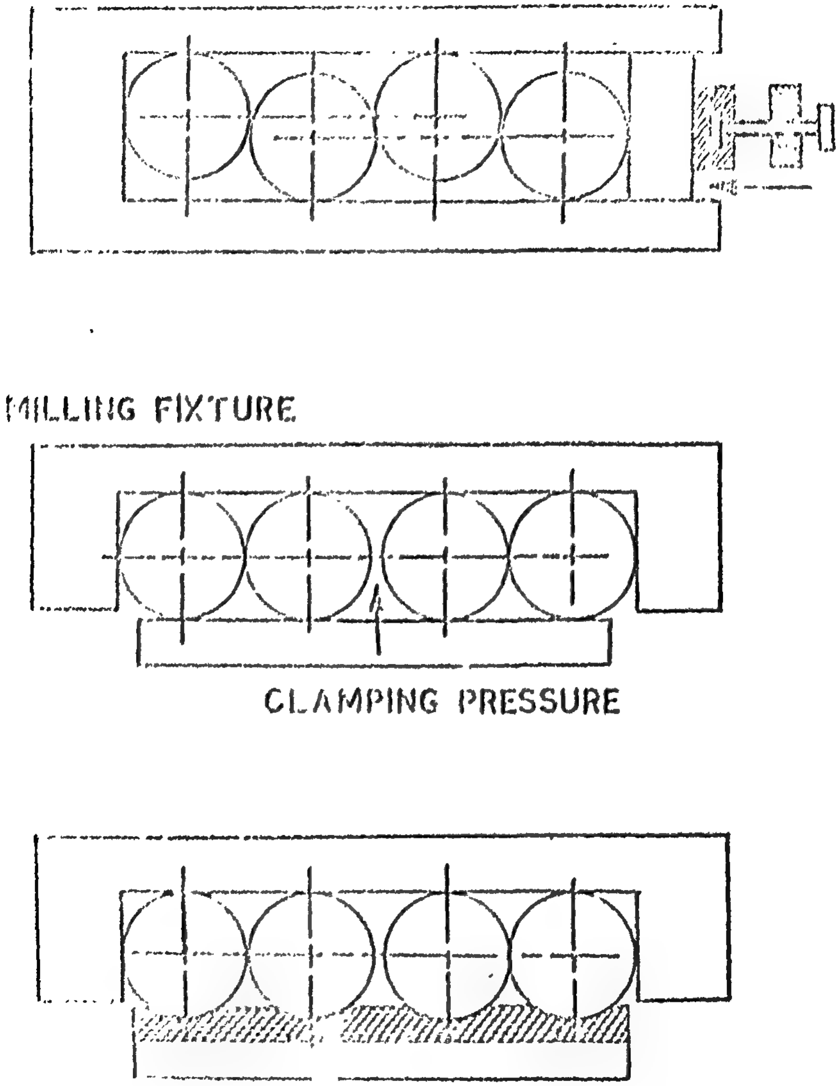

Fig. 14·51

row depends upon the size of the milling machine or its accuracy over a given length of traverse. Unless the machine is provided with a tripping mechanism, enabling the table to pass rapidly the blank

related to the movement of a roller which keeps close contact with the master profile. Thus the profile of the master is reproduced on the component.

Continuous Rotary Milling Fixtures :

The ideal arrangement for milling is with the help of a continuous rotary milling fixture in which the work pieces traverse past or under previously set cutters at the maximum feed consistent with the nature of the material, each one being correctly located and clamped. Such a fixture is designed to give maximum rigidity. The out put by this method is regulated by the operators ability to unload, clean and reload the fixture while it is still revolving and cut

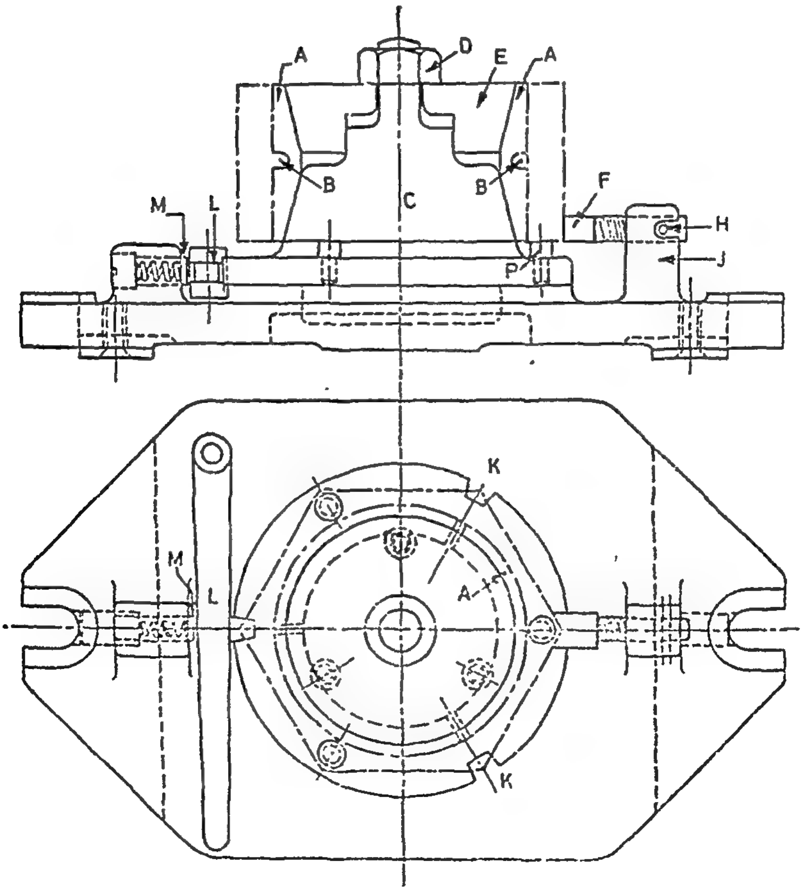

Fig. 14·52

is in progress. Because cutting time for this type of fixture would usually be less than that taken for clamping and un clamping by manual means, some form of automatic clamping is devised. Continuous milling is best carried out on a vertical spindle machine with the fixture located on a revolving table. A rotary milling fixture for milling bosses of a connecting rod is common. The components are arranged radially round the fixture as close as possible, each pair being held by one *C* clamp. A hole previously drilled in the centre of the boss of the connecting rod makes a suitable locating point, for which purpose the shouldered pins are arranged round the fixture. The opposite ends of the pieces are kept in position by the pegs. The setting piece is placed at convenient point and two more are spaced round the fixture for the convenience of the operator. The steel peg in the centre of the fixture is a push fit in the hole in the centre of the revolving table and locates the fixture.

Indexing milling fixtures : A work piece having a number of surfaces to be milled may be successively positioned by a single fixture provided with indexing arrangement Fig. 14·52 is an illustration of such a fixture where the component, a hexagonal iron casting requires machining on six sides, having previously been bored and faced. A few indexing devices are mentioned later in this book.

TURNING FIXTURES

Holding the work pieces for the lathe operations is successfully achieved with the help of numerous type of equipment available commercially. Such equipment can be classified into chucks, mandrels and collets. To meet particular situations there are further modifications of the three broad classes available. Special chuck jaws cau be designed for holding castings and forging for first operations. Expanding mandrels, pegs find great favour with tool engineers especially where the work affords a machined surface of sufficient accuracy to locate them. When components made from bar on automatic lathes require a second operation they may often be finish machined using a spring collect fitted with an internal

stop. However, there still remains a vide variety of components which cannot be effectively held in the above mentioned conventional work holding devices or equipment. Such components require the design of turning fixtures which can be mounted on face plates with the help of dowels and screws. The work pieces are then located and clamped on these turning fixtures for further operations, eliminating the necessity of costly setting. Following points need careful attention while designing turning fixtures :—

1. Grip the rotating workpiece securely to the fixture to resist torsional forces.
2. The fixture should be rigid and overhang should be minimum possible.
3. Locate the workpiece on critical surfaces which are areas from which all or major dimensional and angular tolerances are taken.
4. Provide adequate support for frail section or sections under pressure from lathe tools.
5. Fixture should be accurately balanced to avoid vibration at high spindle speeds.
6 Fixture should be free from projections likely to cause injury to the operater.
7. A pilot bush for supporting tools should be provided where extreme accuracy is required in boring operations.

Face Plate Fixture : It is a common type of turning fixture. which is usually fastened to the lathe face plate or back plate. It incorporates conventional fixture clamping and locating devices for holding a work piece. A shallow counter bore in the lathe face plate receives a fixture back plug to locate the lathe fixture on the lathe spindle centre line. The fixture is secured to the face plate by cap screws inserted though the fixture into tapped holes in the face plate or by T bolts inserted into T slots in the face plate. On high speed lathes, the fixture with a workpiece in place should be dynamically balanced as accurately as possible. The face plate

itself is either bolted to spindle flanges or screwed on to spindle nose depending upon the type of machine spindle. A face plate fixture for turning a bracket, bottom face of which is milled and is used for locating is a common turning fixture. Fixture design takes care of the critical distances and work piece needs no centring of any kind.

GRINDING FIXTURES

Some sort of fixtures are required for all types of grinding operations. Cylinderical grinding utilises mandrils for external grinding of surfaces. The mandril may be plain or tappered. For internal grinding operations chuck is the most standard fixture. Special jaws as in lathe may be fixed here also for holding castings and forgings. An equipment that is useful in grinding operations where job cannot be adequately held is the magnetic chucks. It is available in a form which can be set on the cylinderical grinding machine but it finds its maximum use in vertical surface grinders and it is of rectangular shape. This chuck is available for use on reciprocating table.

Surface grinding operations require fixture of the same type as used in milling. Surface grinders with rotary table use continuous rotary fixtures whereas surface grinders with reciprocating table use both plain and string fixtures. Job in both cases may some times be held simply in a magnetic chuck. Fixtures for surface grinding are equipped with setting block and tenon strip etc. If the fixture is to be clamped to machine table. A few problems of interest for a designer while designing grinding fixture are :

1. Coolant nozzles, spray guards, part feeders and other such devices.
2. Coolant escape or control :
   (a) Coolant delivery through the fixture to the work-piece.
   (b) Coolant and sludge escape from the fixture.
3. Mounting of wheel dressers on or close to be fixture.

4. Rotating fixtures and chucks generally require dynamic balancing.

BORING FIXTURES

Boring operations can be classified in two ways (*a*) Boring bar rotates in the work (*b*) Work rotates around the boring bar. Boring fixtures for the first classification are designed similar to drilling jigs when the boring bar is guided in a bush called pilot bush. A bush is necessary in advance of the tool also for steadying and centralising the boring bar in case of long jobs. Vertical boring machines operate on the second classification and can utilise fixtures similar to lathe. Horizontal boring machines also work on the same principle some times.

Boring fixtures do not normaly require to be as rigidly constructed as the milling fixtures, because the load imposed by the boring tools rarely approaches that introduced by a milling cutter. Boring bars are made of mild steel, case hardened and ground. When rough turning them however additional material approximately 5mm over the finished diameter of the bar should be left adjacent to the tool holes, so that after carburising this surplus material may be removed and the hole or slot then bored or cut. By adopting this method there will be no hardened surfaces at these points. This helps to prevent fracturing and also permits any slots or holes to be trued up after the dipping off for hardening during which they are likely to be distorted.

It is sometimes desirable when boring large diameters inside a component, to provide one or more loose boring heads which can be attached to the boring bars and so prevent the excessive over hang of the tools which would otherwise occur.

BROACHING FIXTURES

In the recent years broaching operations have found extensive applications in the production of key ways, round holes, holes and gears. Broaching operations are of two kinds, (1) internal broaching or (2) surface broaching. Again a broach may either be pushed

or pulled. The fixture used for internal broaching Fig. 14.53 consists solely of a hardened bush. peg or similar device. The bush or peg is located in the machine table and the broach is either pulled or pushed. Pull broaching is generally used instead of push broaching because length of a push broach acts as a long column which may buckle or break. Surface broaching fixtures range from the simple hand operated type, to the complex hydro-machanical type designed integral with a hydraulically operated broaching machine. A large variety of work pieces of numerous shapes and materials are now machined by surface broaching. Consequently in companies engaged in the large production of small parts by surface broaching, the tool designers find a considerable portion of their time taken up by the design of these fixtures. Many of the principles of milling fixtures may be applied to the design of surface broaching fixtures. A few essentials about surface broaching fixture design are :

1. All elements of the broached surface must remain parallel with the broach axis.
2. Walls of the part being broached must be sufficiently heavy or adequately supported to withstand the pressures of the operation.
3. The amount of stock to be removed by the broach must be consistent and controlled within reasonably close limits.
4. There must be no obstructions in the plane of the broached surfaces.

It is general in surface broaching to design broaches as inserts about 250mm long which can be easily produced and easily replaced in case of damage or wear. These inserts are then assembled in broach holders to produce the desired shape in the finished part.

ASSEMBLY FIXTURES

Assembly fixtures are of two types :

1. Mechanical assembly fixtures for operations performed at ordinary (room temperature) with mechanical means. Riveting fixtures such as in wagon assembly shop are most common type of mechanical assembly fixtures. Two or more parts are held together

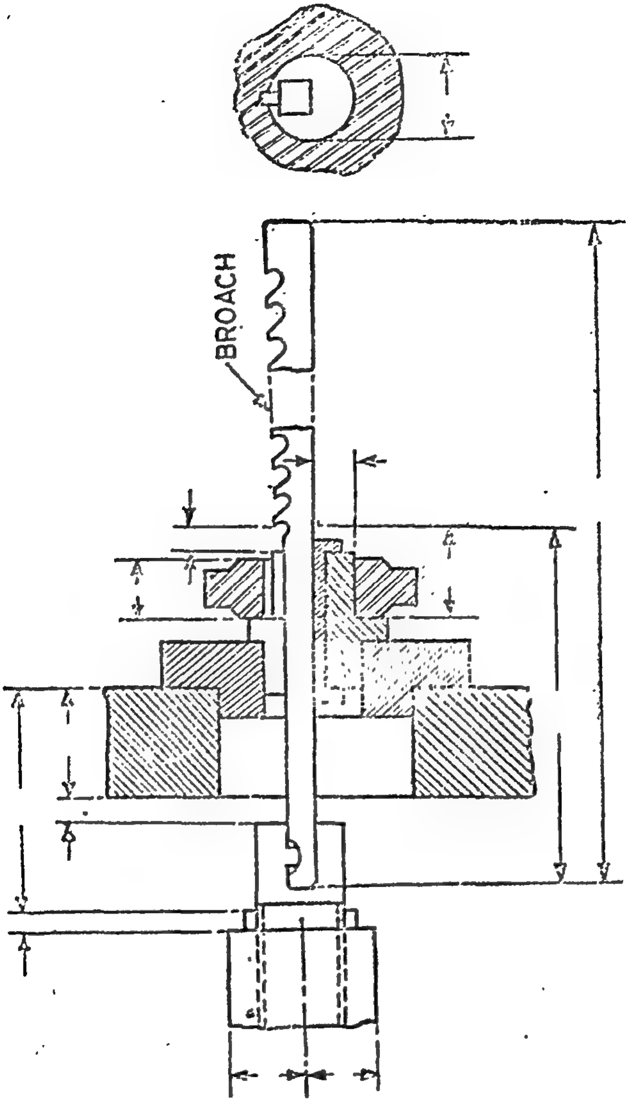

Fig. 14.53

in predetermined positions and they are riveted by pneumatic rivetors.

2. Fixtures for hot joining methods of assembly work use energy in the form of heat. All welding fixtures come under this category. Welding jigs and fixtures may be tacking jigs, welding fixtures, holding fixtures, resistance welding fixtures, soldering

and brazing fixtures etc. Primary function of such fixtures is that of holding and orienting work pieces for their correct joining. Except for electrode pressure, fixtures need not be designed to withstand the torque or other forces of cutters, drills and other tools. Stresses resulting from thermal expansion of work pieces and for fixtures must be considered in the design of clamps and locators and in the proper positioning of the work pieces before and during assembly, depending upon the necessary distribution of heat to the work and fixture. Fixtures for some operations must absorb considerable heat and provide clamping pressure to prevent excessive thermal expansion of the work and of fixture elements. Some metals which have a tendency to crack near the weld when tightly clamped should be tack welded when clamped and finally welded without a fixture.

WELDING FIXTURES : are grouped into three classifications viz tacking jigs, welding fixtures and holding fixtures.

A tacking jig locates the components of a weldment in their correct relationship properly clamped, while a tack welder tacks them together prior to their final welding. The tacked assembly is then moved to another fixture for full welding. Tacking jigs are not affected by thermal heat as very little hot work is done on these jigs.

A welding fixture properly locates and holds work pieces for complete welding operations. A welding fixture must withstand thermal pressures due to welding operations. Locations and clamps should not loose accuracy due to heat effect. However sometimes it is not possible to achieve this accuracy due to excessive thermal effects. Best practice therefore is just tack weld first and then transfer it to another fixture called holding fixture for final welding. In this way tacking jigs remain accurate enough.

A holding fixture holds previously tacked assemblies in place on a positioner. The fixture itself can after be adopted for positioning by the addition of a trunion stand with index plate and plunger of suitable design. Like welding jig, the holding fixture must be strangly and rigidly constructed to withstand the commulative stresses generated within the work piece in the process of welding. For safe handling, fixture should be kept cool with air, water. It must be insulated for heat.

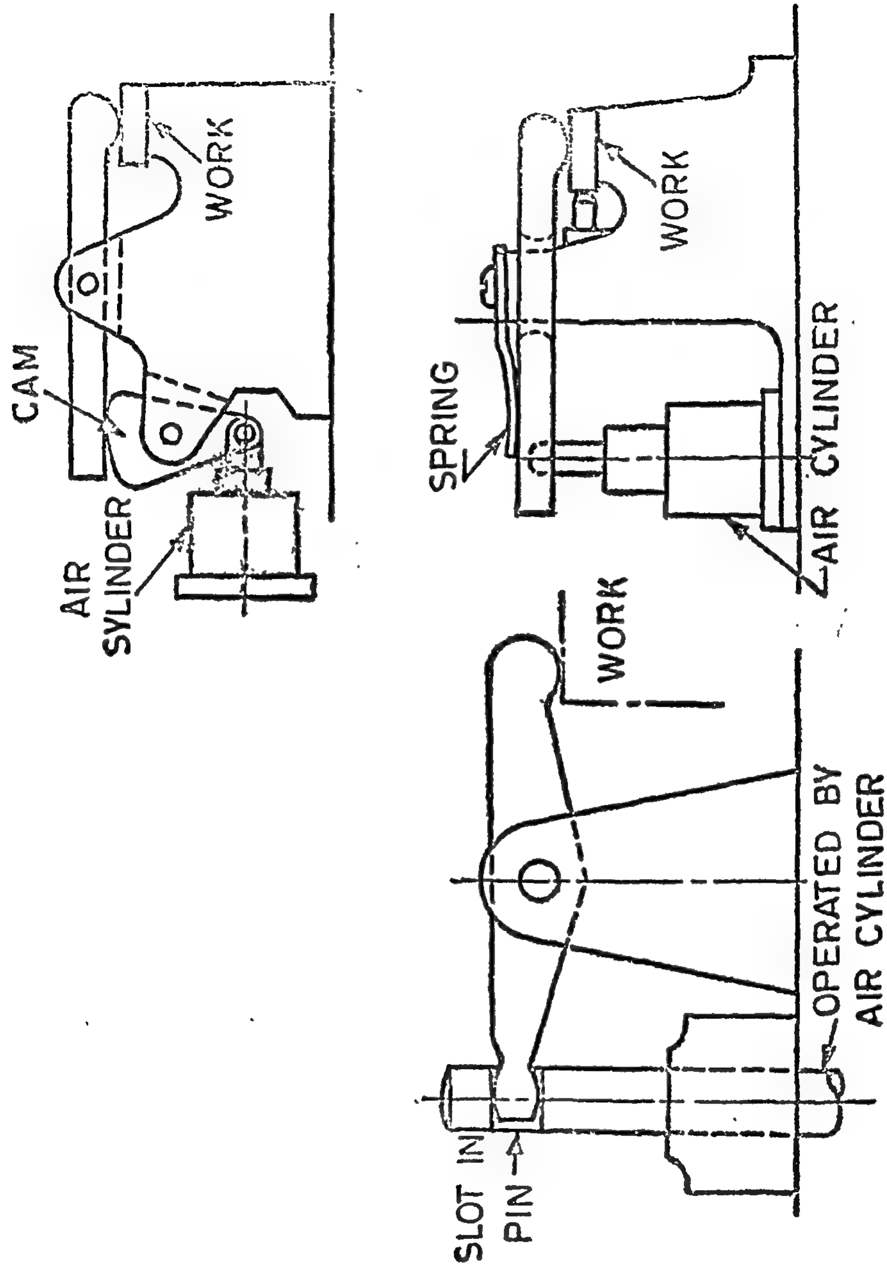
CAM
WORK
AIR
SYLINDER
SPRING
WORK
AIR CYLINDER
WORK
SLOT IN
PIN
OPERATED BY
AIR CYLINDER

Fig. 14·54

Hydraulic and Pneumatic clamp Actuation :

Applications of pneumatic or hydraulic pressure to actuate clamps, instead of manual pressure can be fully justified due to several reasons :—

1. The average ratio of chucking time between manual operation and air or hydraulic operation is 4 to 1.
2. Pressures are uniform and are controlled by the operater with minimum fatigue.
3. Where several clamps are used in one fixture, arrangements can be made usually to close them simultaneously by air or hydraulic means.
4. Comparatively small force is available from hand clamping.
5. High working pressures enable the size of hydraulic or pneumatic installation to be relatively small and compact.

The advantages of power actuated clamps have brought about their wide use especially for large scale production. Force can be applied directly from a piston rod for clamping but it is considered better practice to transmit the force through a linkage that is self locking and steps up the force. Fig. 14.53 (*a*, *b*, *c*, *d*) If the air or hydraulic pressure should fall off at a critical time, the self locking feature keeps the clamped object from becoming loose. The use of mechanical advantage allows a lower pressure for the same size of cylinder than would be needed if there were no advantage. Clamping pressure should be applied to the rod side of a piston, and the releasing pressure to the full area. The force for release will thus be greater than clamping and there will be less likelihood of sticking of clamps.

Pneumatic or air operated devices are classified as piston and diaphragm devices.

Piston devices :

Compressed air at a pressure of 5 to 10 kg/cm^2 is supplied

its initial position and to released workpiece. Use of a piston device for actuating the clamping system is shown in Fig. 14.53.

Diaphragm Devices :

They have a cast iron housing between the halves of which a diaphragm of rubberised fabric or corrugated sheet metal is clamped. From one side the steel disc linked to a clamp actuating rod is held against diaphragm by the spring pressure. Compressed air enters the recess behind the diaphragm which is forced towards the disc and rod. This compresses the spring and actuates the rod. When air is released, rod is returned to its initial position by the spring pressure. Diaphragm devices have some advantages over piston devices in that they are 2. Simple and cheaper Smaller in size. provide longer service due to the absence of friction surfaces. However their small effective stroke is a disadvantage. (fig. 14.54a)

Apart from the built up cylinder of the piston devices or diaphragm device a complete pneumatic equipment includes the following items :—

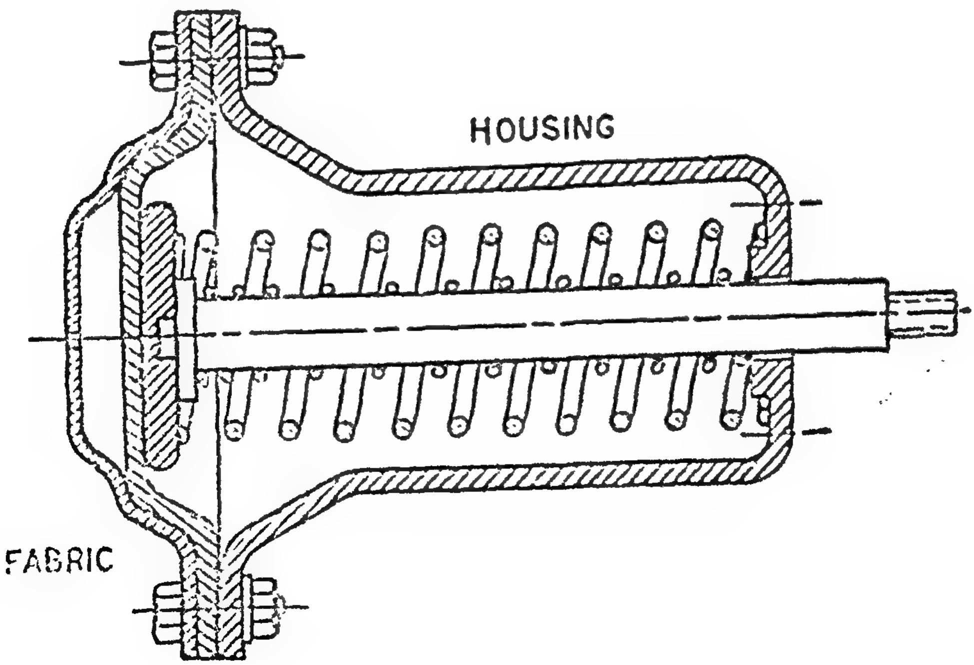

Fig. 14.54a

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Preface to Second Edition

The authors present an enlarged and revised edition of the text book of Production Engineering. The book has been rewritten with a view to meet demands of present day industrially oriented courses in undergraduate curriculum. Ten new chapters have been added to the earlier edition to make it a comprehensive text book for the degree students of several Indian Universities. The book should also serve a preparatory book for the post-graduate students in production and Industrial Engineering courses.

Authors

Roorkee
Jan. 1, 1972.

PREFACE

This book is intended as a text book for both Undergraduate and Post-graduate courses in the field of Production Engineering. The importance of teaching Production Engineering subjects has now been realised by engineering faculties. With the result, the subject has been introduced either as an elective or especialised subject in mechanical engineering curricullum in all engineering colleges under different names. The book has been written to cover these syllabil of various institutions in the country. The contents of these topics are generally dealt with in final year classes. The book is specially useful for students preparing for degree in Production Engineering, Advanced Diploma in Production Engg. and Institution of Production Engineers, London examinations in two separate subjects of Machine Tool Engineering and Tool Design.

The book deals with two distinct aspects of Production Engineering. Even though the chapters have been intermingled. First aspect deals with Machine Tools and Metal Cutting (Machine Tool Engg.) and second aspect deals with jig fixtures, tools and dies (Tool Design). Thus the book is useful for two distinct courses for a regular degree in Production Engineering.

Machine tools and metal cutting part deals with principle of metal machining, theory of machinability, cutting tool materials, fundamentals of machine tools, method of gear cutting, screw cutting etc. and the subject has been dealt at high level suitable for post-graduates classes.

Tool design section starts with process planning and develops the subject in the manner in which the design function is carried in tool design offices. Having determined the need for tooling equipment in process planning sheet, the design principles of all tooling equipment such as jigs and fixtures, press tools and forging dies, gauges, turrets and automatics have been discussed in detail. An attempt has been made to familiaries students with procedure of estimating also. Quizes and problems have been added at the end of each chapter for the benefit of students. We hope

the students will find the book very useful as a text in productions engineering.

Lastly, we express our indebtedness to the authors and publishers of books which we have consulted. Further this work is just an effort for—making—the subject simple for readers. Suggestions for improvement will always be appreciated.

Authors

Roorkee
Chandigarh,
30th Sept. 1967.

CONTENTS

PART ONE : METAL CUTTING & MACHINE TOOLS

CHAPTER I

GEOMETRY OF CUTTING TOOLS

Upto the end of nineteenth century metal cutting was more of an art rather than a science. Each machinist had his own way of machining the metal and grinding the cutting tools. Many of methods were primitive. A change in the existing trends of machining was noted at the beginning of this century when the metal machining was viewed in a scientific manner due to many sided work of notable persons like Thimme (U.S.S.R.) and Taylor (U.S.A.). Thimme formulated the principle laws of metal cutting and Taylor besides laying down the principles of management, did some fundamental work on the tool life and cutting velocity relationship. Due to this humble start people in shop and the production engineers realized the importance of doing the job on a rationale basis rather based on their intuition. The first thing that received their intention was the cutting tool; as such better tool materials were developed and the role of tool angles and signature was realized. In this chapter a few illustrations have been described regarding the cutting tool geometry as is now widely understood by shop people and research engineers.

10·1 MAJOR KINDS OF CUTTING TOOLS

Cutting tools can be broadly classified into two major groups—single point cutting tool and multi-point cutting tools. Single point tools are used on lathe, shaper & planer and multi-point cutting tools are used on milling machine, broaching machine etc., Multi-point cutting tools may be treated to be composed of two or more than two cutting tools.

Single point cutting tools have been further classified intc ree subgroups, *viz*., solid tool brazed tool, and inserted bit tool. g. 1.01). The solid tool is made from H.S.S. or carbide bar and ; cutting edge is prepared by grinding.

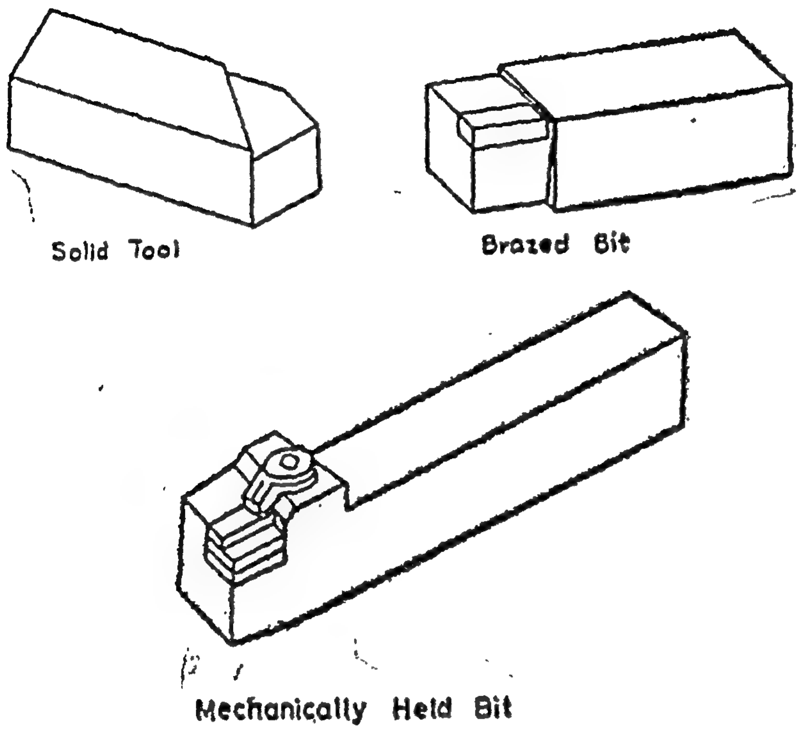


Fig. 1.01. Major kinds of single point cutting tool

The brazed tool has a shank of high strength steel and a bit of S.S. carbide or stellite brazed over the shank to form the cutting ;e. Recent trend is to have the tools with mechanically held erts of carbide or ceramics. Such tools offer many advantages.

(*i*) The cost of tool preparation is eliminated.

(*ii*) An insert requires a very small amount of cutting tool material. The cost of tool is considerably reduced, thus.

(*iii*) Inserts can be easily removed from the holder and thus the tool changing cost is reduced.

(iv) The ill-effects of heat due to grinding and brazing are eliminated.

(v) The inventories are reduced and simplified, as well.

1.02 A SINGLE POINT CUTTING TOOL

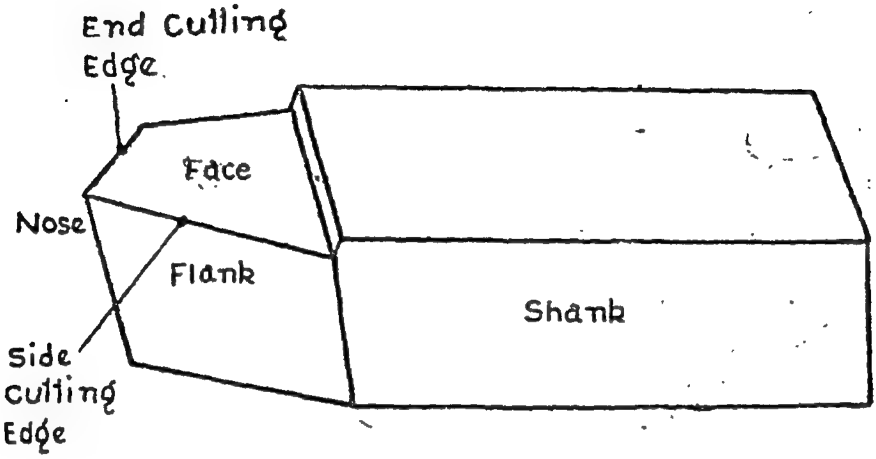


Fig. 1.02. Single Point cutting tool and its nomenclature

A single point tool has one cutting edge which is formed partially by the end cutting edge and largely by side cutting edge. The nose is usually given a radius and very seldom it is like a sharp point. Its shank has a rectangular section but in normal cases the section is square.

In order to define the geometry of a single point tool it is necessary to define some reference planes so as to locate the parameters of the cutting tool.

1.03 REFRENCE PLANES

A single point tool in action during a turning operation can be represented as in fig. 1.03 in reference to three mutually perpendicular planes-cutting plane (l), orthogonal plane (n) and base plane (m). The cutting plane is a vertical plane which is tangent to the cutting surface and the cutting edge of the tool lies in this plane. The orthogonal plane is also a vertical plane which crosses the cutting plane at right angles. The third plane which is termed as base plane is a horizontal plane which is perpendicular to both the above planes and is parallel to the longitudinal feed and cross feed of the tool.

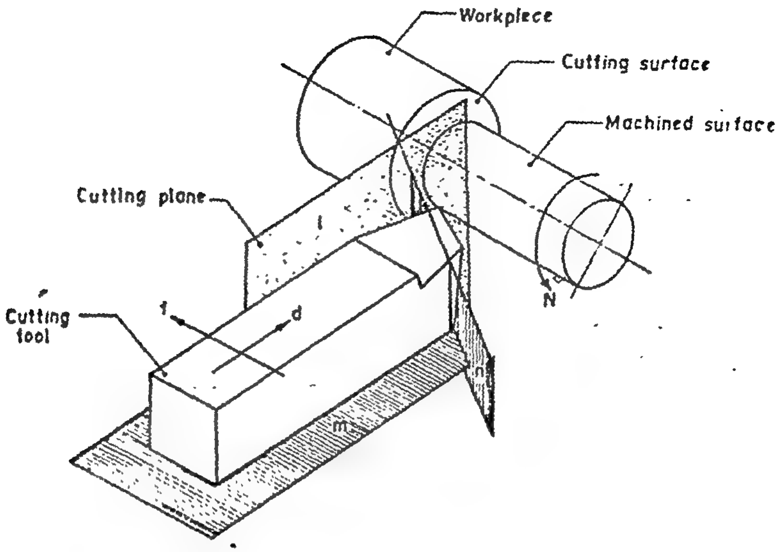


Fig. 1.03. Tool and work piece in *lmn* planes

All the angles of the tool for the analytic treatments have been defined in reference to these planes. However those persons who

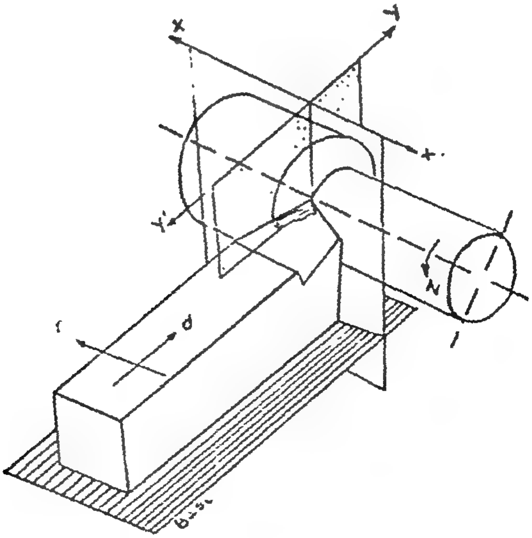


Fig. 1.04. Tool and work in *x-y-z* planes.

work on the shop floor understand very little with this kind of representation. They follow another system of defining the cutting tool so that they can grind and prepare the tools. This kind of practice is adopted in the U.S.A. where geometry of the tool is defined in reference to three mutually perpendicular coordinate planes (x-y-z) Fig. 1.04

1.04. TOOL GEOMETRY IN lmn PLANES

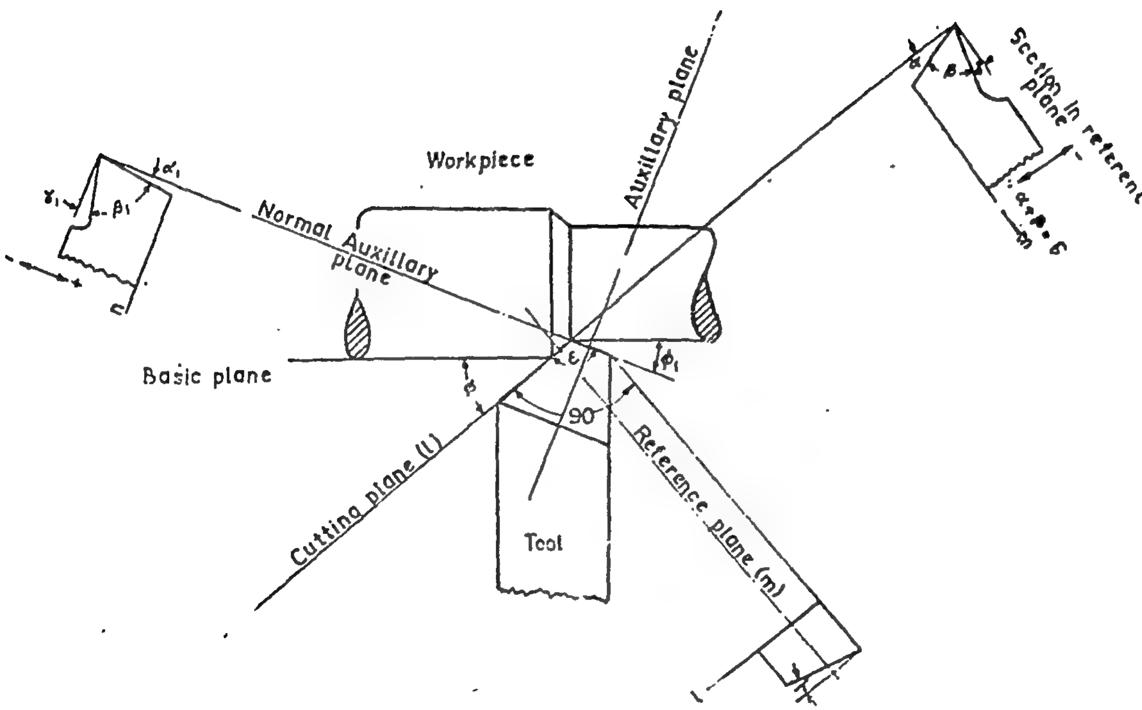


Fig. 1.05. Tool angles in *l-m-n* planes

γ=Orthogonal rake angle — γ_1=Side rake angle

β=wedge angle — β_1=Side wedge angle

α=Side relief angle — α_1=End relief angle

ϕ=Plan approach angle — ξ=nose angle

δ=Cutting angle — ϕ_1=Auxillary cutting angle

λ=Inclination angle

1.05 TOOL ANGLES ON X-Y-Z PLANES

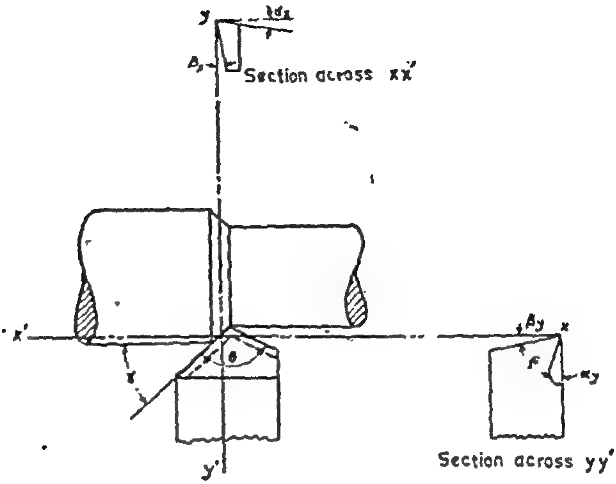


Fig. 1.06. Tool angles in x-y-z planes

α_y=Top rake angle
α_x=Side rake angle
β_y=End clearance
β_x=Side clearance
ξ=Edge angle
θ=Plan angle
ϕ_s=Side cutting edge angle
ϕ_1=End cutting edge angle

The practical way of describing the tool is by numerals shown in fig. 1.07.

1.06 Inter-relationship in the angles on *l-m-n* and *x-y-z* systems

$$\tan \gamma = \sin \phi \tan \alpha_x + \cos \phi \tan \alpha_y$$

$$\tan \lambda = -\cos \phi \tan \alpha_x - \sin \phi \tan \alpha_y$$

$$\tan \alpha_x = \sin \phi \tan \gamma - \cos \phi \tan \lambda$$

$$\tan \alpha_y = \cos \phi \tan \gamma + \sin \phi \tan \lambda$$

Proof :

$$\frac{a}{A}=\tan \alpha y \quad \frac{c}{C}=\tan \lambda \quad \frac{b}{B}=\tan \gamma$$

$$\frac{d}{D}=\tan \alpha x$$

Also $a=b+c$

therefore, $\quad A \tan \alpha y=C \tan \lambda+B \tan \gamma$

$$\text{or,} \quad \tan \alpha y=\frac{C}{A} \tan \lambda+\frac{B}{A} \tan \gamma$$

$$=\sin \phi \tan \lambda+\cos \phi \tan \gamma$$

Similarly, other relations could be derived.

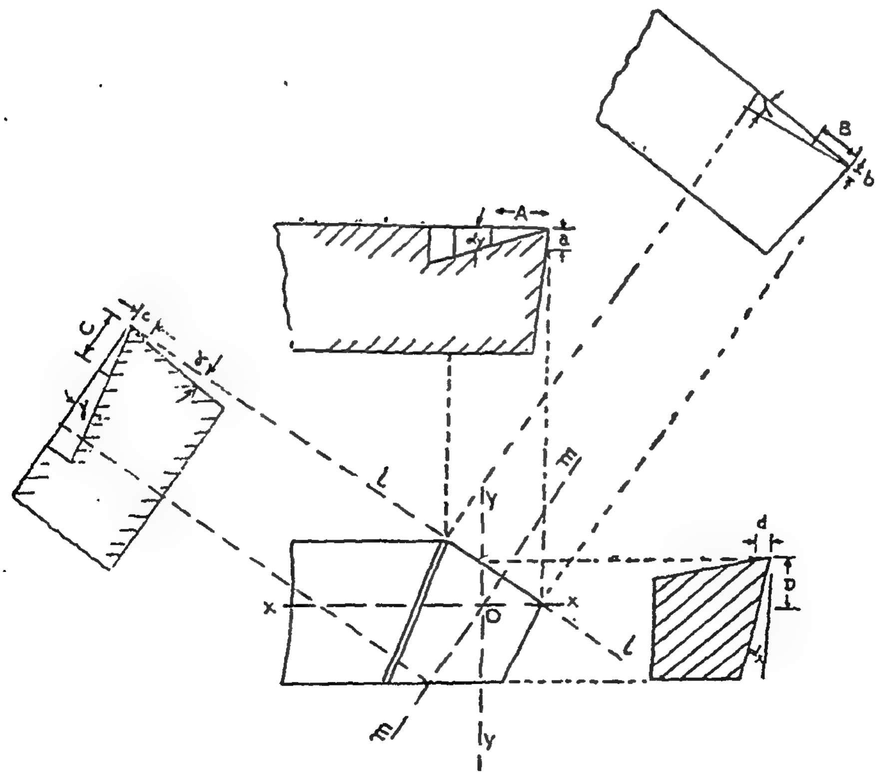


Fig. 1.08 Angle relationship in two systems.

1.07. Effect of plan approach angle on undeformed chip thickness and width of chip.

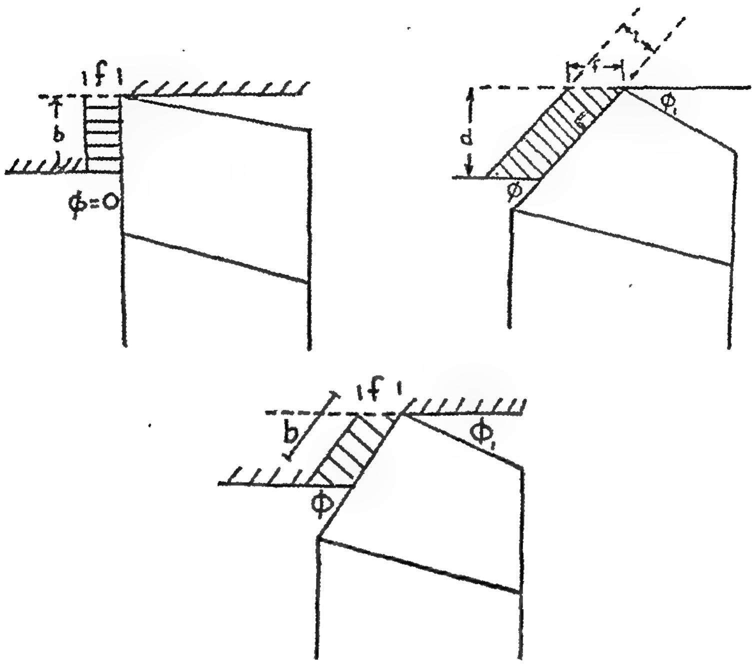


Fig 1.09

Let t=chip thickness, mm.

s=feed mm/rev.

d=depth of cut, mm.

b=width of the chip.

We have

$$t=s \sin \phi$$

$$\frac{d}{b}=\sin \phi$$

$$\therefore \quad b=d \operatorname{cosec} \phi$$

When ϕ is zero, the chip thickness is equal to feed and when $\phi \neq 0$ it is never equal to feed and is obtained by above relationship.

1.08 POSITIVE AND NEGATIVE RAKE TOOLS

With the introduction of carbide tools, quite often tools with negative rakes are also used. Certain advantages have been derived with negative rake tools.

Negative rake tool offers more strength to the cutting edge since the bit is almost subjected to pure compression where as in positive rake the conditions are those of shearing and bending. Since carbide possesses a very high value of compressive strength,

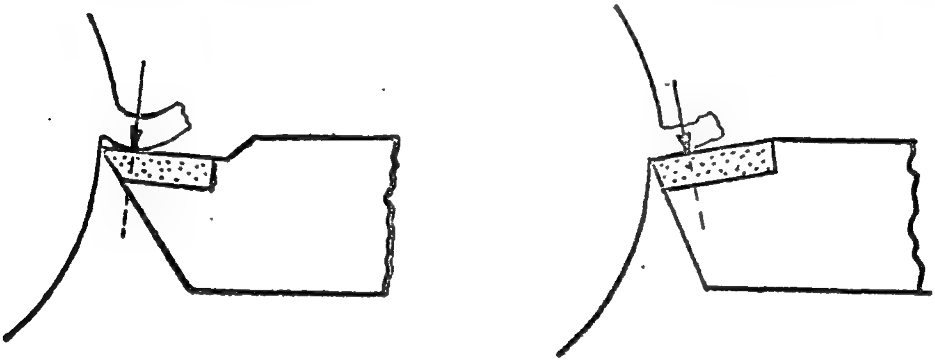


Fig. 1.10 Positive and Negative Rake Tools

negative rake tools prove more useful and improve the cutting action of the tool. As a result the tools can be safely used when interrupted cuts are taken or when harder materials are machined at high speeds and feeds. Negative rake also reduces the depth of crater due to its effect on chip flow and curl on the face.

1.09 DRILL GEOMETRY

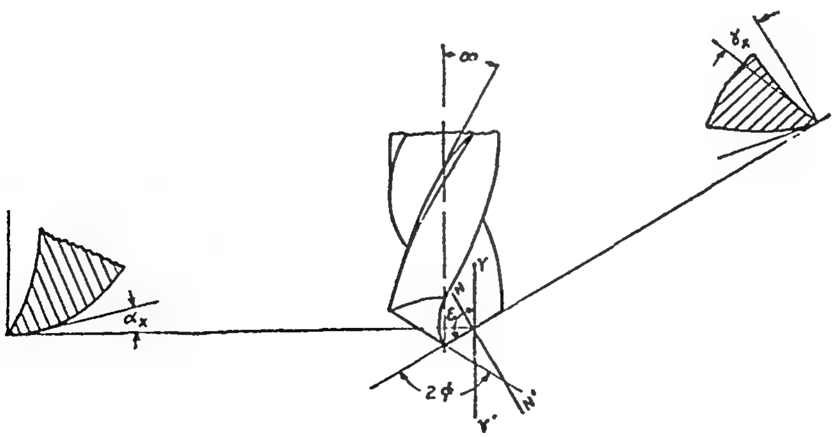


Fig. 1.11 Angles on a Drill

In Fig. 1.11 the main angles of the drill *viz*-, : rake angle γ, the lip relief angle α, the point angle 2ϕ and the chisel point angle have been shown. The value of γ changes from chisel point to the periphery. Therefore, while determining this angle its location should be clearly specified. The usual values of these angles are.

$$\gamma_x = 1^\circ - 5^\circ \text{ at the chisel point (it is variable)}$$

$$\alpha_x = 8^\circ - 10^\circ \text{ at the periphery}$$

$$2\phi = 116^\circ - 120^\circ \text{ for soft materials}$$

$$130^\circ - 140^\circ \text{ for hard materials.}$$

$$\varphi = 50^\circ - 55^\circ$$

$$\omega = 45^\circ \text{ for non ferrous materials}$$

$$30^\circ \text{ for ferrous materials}$$

An important relationship is

$$\tan \gamma_x = \left(\frac{Dx}{D}\right) \frac{\tan \omega}{\sin \phi}$$

Example :

Calculate orthogonal rake at 12° mm diameter for a 20 mm dril having an helix angle of 30° and $2\phi = 118°$

Given : $Dx = 12$ $\quad D = 20$

$\omega = 30^\circ$ $\quad \phi = 59$

$$\therefore \quad \tan \gamma_x = \left(\frac{12}{20}\right) \frac{0.577}{0.857}$$

$$= 0.404$$

$$\gamma_x = 22^\circ$$

1.10 GEOMETRY OF A MILLING CUTTER

Out of a large variety of milling cutters used in milling practice, two very simple types of cutters have been choosen to describe the geometry of milling cutters. Fig. 1.13 represents a plain milling cutter of high speed steel and Fig. 1.14 represents a

face milling cutter with inserted carbide bits in it. The various angles as are commonly used in reference to milling cutters are indicated on the figures.

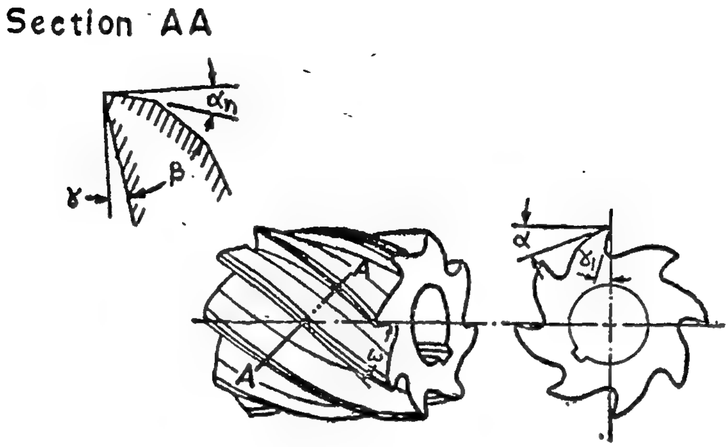


Fig. 1.12 Plain Milling Cutter

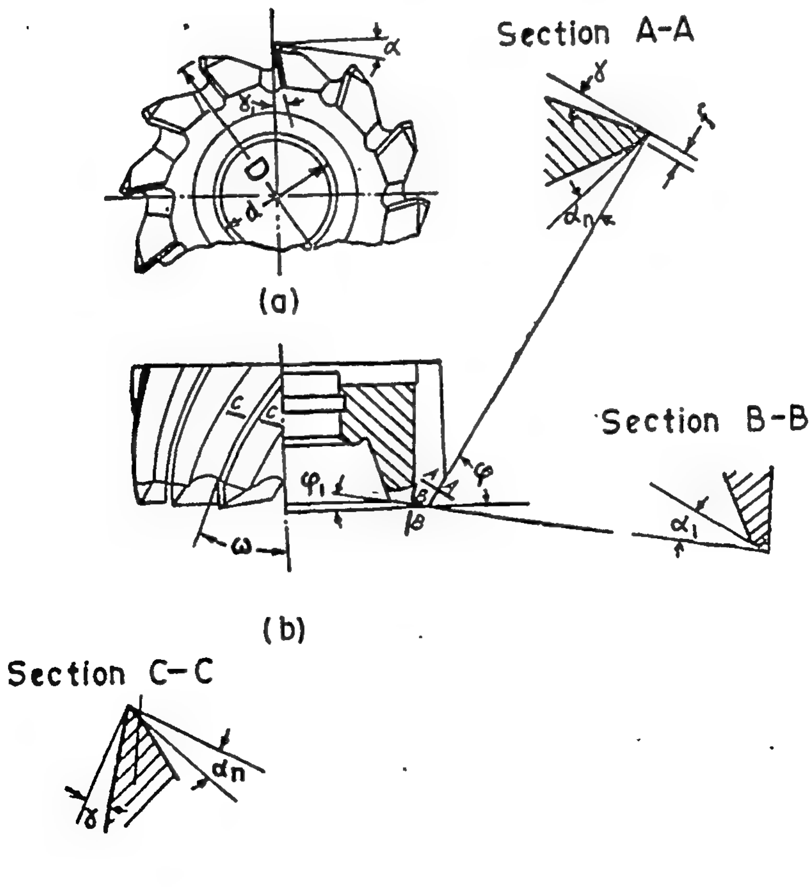


Fig 1.13. Face milling cutter of high speed Steel

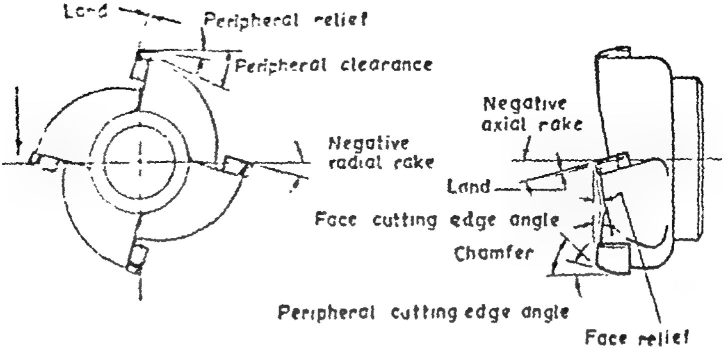


Fig. 1.13 Face Milling Cutter with bragzed tips

1 11 KOLESOV TOOL

It is a particular type of single point tool named after its orignator V. kolesov. He developed a geometry for the single point tool (fig. 1 14) due to which it was possible for him to use the tool at heavy feeds. It is a bent type straight turning tool. Three cutting edges have been provided on it. The cutting edge, equivalent

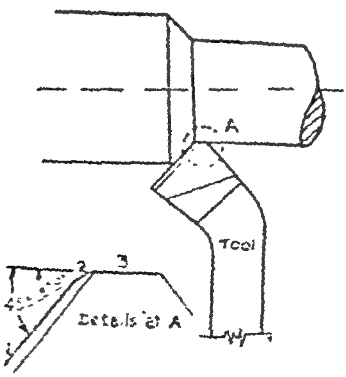


Fig. 1.14 Kolesov Tool

to the side cutting edge having an approach angle of 45° to the work axis. The intermediate cutting edge 2 is approximately 1 mm wide and it has an approach angle of 20°. The third edge 3 is 0·5 mm larger than the feed rate and is parallel to work axis. Main cutting is done by the first edge. The third edge performs the finishing action to provide better finish. The intermediate cutting edge is only to avoid the sharp nose point parameters so that they can easily form the geometry by grinding.

QUIZ

1. What are the major kinds of tools ?
2. State the advantages of mechanically held inserted tools.
3. What is the importance of describing the tool geometry in *xyz* planes ?
4. Prove that $\tan \alpha = -\cos \phi \tan \alpha_x + \sin \phi \tan \alpha_y$.
5. Describe a tool with 10, 10, 6, 6, 8, 8, 1mm signature in A.S.A. System.
6. Explain the functions of three edges in a Kolosov tool.

CHAPTER 2

PRINCIPLES OF METAL MACHINING

2 00 METAL MACHINING

The process of machining is usually employed for shaping the workpiece of metal according to the preset dimensions of the component. It removes the unwanted material from the workpiece in the form of chips. No doubt, metal can be effectively shaped by a large number of other manufacturing processes, even then machining occupies a prominent place in engineering industries as it enjoys one supreme advantage over the other processes—'machining is a versatile process'. Its versatality can be counted on so many factors. Some of which are :

1. Machine Tools do not require elaborate tooling.
2. Machining can be employed to a large number of other materials, also.
3. Tool wear is not a costly item, if it is kept within tolerable limit.
4. A large number of parameters govern machining operation. The parameters can be suitably manipulated to overcome technological and economical difficulties.

With all the above points in its favour machining might have been placed at the top of all the manufacturing processes, but for one fact that the chips have little value. On this point, the process has been remarked as a 'wasteful process' from certain quarters. Even then, it has never been possible to eliminate machining from the industries. This fact has led to study the machining process with respect to every factor influencing the rate of metal removal and economy of the process.

2·01 Chronogical Review of Mechanics of Machining processess.

Analytical and experimental studies of the cutting aspects of the machining processes have been made for over one hundred years. These studies have been very profuse in the last thirty years and it appears that they shall continue to be so in the immediate future. Earlier studies were mainly concerned with chip formation, cutting force and power measurements. The first attempt in this field was made by Cocquilhot in 1851 who worked on drilling of materials and work done in the drilling process. In 1865, Joessel conducted an investigation on the influence of tool geometry on cutting forces. The name of Tresca (1873) poineer in the study of plastic flow of metals is also mentioned in the literature, who while employing his theory of plasticity described the cutting process wrongfully as that of compression ahead of tool. It was Thimme who contradicted this fact in 1877 and pointed out that the material is not being compressed ahead of tool but is sheared along a plane, which he termed as shear plane. He was the first man who established the very well known geometrical model of cutting process and shear angle relationship. At the same time Mallock (1881) also devoted considerable time in studying chip formation mechanism and tool face friction with and without coolant. A good amount of analytical work was reported by Zvorykin (1893) on to forces and stresses employing shear plane model which was later on criticised by his own countryman Bricks (1896) who suggested a series of shear planes at the deformation zone.

At the outset of this century F.W. Taylor published a book on "On the art of metal cutting' which consisted a vast amount of his observations on machinability and tool life. In mid 1920's the term machinability was introduced by Herbert, Rosenhain and Sturney. Piispanen, a finish engineer, (1936) analysed a shear plane model on card analogy analogus to preferred shear plane

From 1935 starts a new era with the poineering work of Erns Martelloti and Ernst & Merchant The former group studied and classified chip formation and the later group developed the mechanics of metal cutting in a systematic manner. At this time another notable workers from university of Michigan Broston and Schmidt made a series of contribution on the machinability of light metal

alloys by calorimetric method. Notable contributions towards understanding of shear mechanism were made by Shaw (196[illegible]) Kobayashi & Thomsen (1959), Palmer & Oxley (1951) and Okushima and Hitomi. Zorev (1963) did extensive work on the nature of friction at tool chip interface and Dawihl (194[illegible]), Trent (195[illegible]) Loladze (1961) and Opitz (1963) contributed many theories on the tool wear. Shaw (1955) and Trigger & Chao (195[illegible]) did some excellent work on the theoretical and practical investigation on temperature distribution and heat in metal cutting.

2·02 ELEMENTS OF MACHINING

The complete machining process is composed of four elements: fig. (2.01)

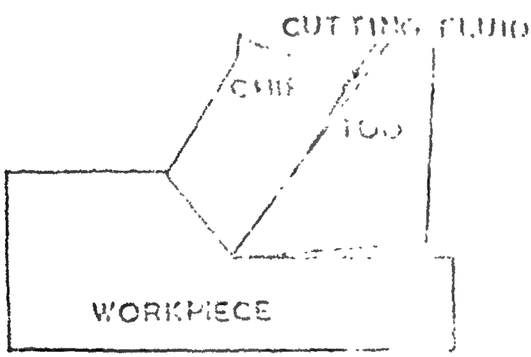


Fig. 2.01 Elements of Machining Process

1. **Workpiece** —besides; it also includes prime-mover and workholding devices.
2. **Tool** —besides, it also includes tool holding devices.
3. **Chip** —
4. **Cutting Fluid**

The associated fields of interest related with of the above four factors are

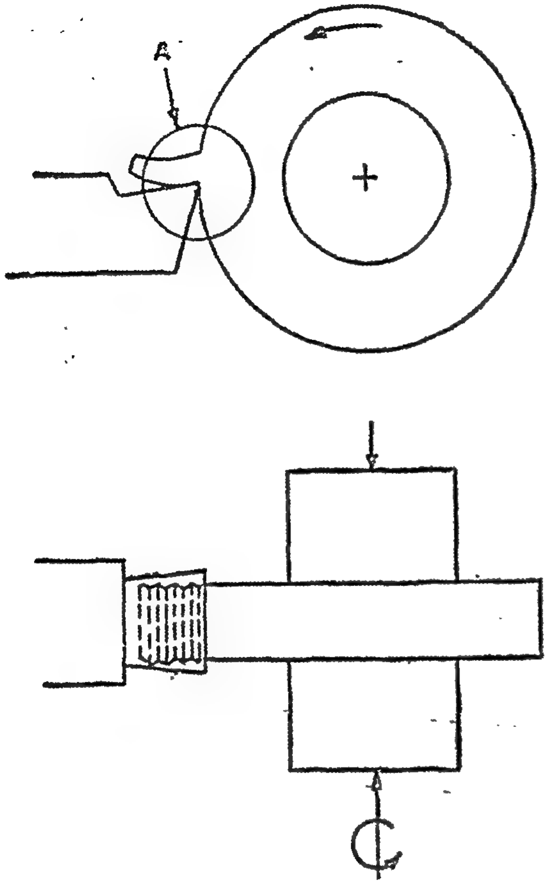
(*a*) **Workpiece**; Its shape and size (for continuous and intermittent cutting,) the chemical composition and mechanical properties.

(*b*) **Tool** : Material and geometry, nature of cutting forces and tool wear.

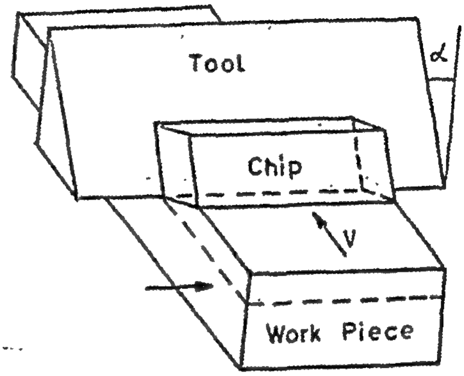
(*c*) **Chip** : Types of chips and the geometry.

(*d*) **Cutting Fluid** : Its chemical composition and rate of flow.

2·03 CLASSICAL METAL MACHINING PROCESSES



(a) Orthogonal Cutting model for Turning Operation



(b) Enlarged View of zone A

Fig. 2 02 Orthogonal Cutting System

For the sake of analysis all the machining processes have been classified into two systems.

Orthogonal cutting systems (*fig.* 202)

Oblique cutting system (*fig.* 203)

The essential features of orthogonal cutting are.

(i) the cutting edge of the tool is perpendicular to the direction of tool travel.

(ii) the cutting edge clears the width of the workpiece on either ends.

(*iii*) the tool prepares a surface which is parallel to the work surface.

(*iv*) the chip flows over the tool face and the direction of chip flow-velocity is normal to the cutting edge.

(*v*) only two components of the cutting forces are acting on the tool, which are perpendicular and can be represented in a plane, and

(*vi*) the maximum chip thickness occurs at its middle.

Such a cutting system is also known as *2-Dimensional cutting*.

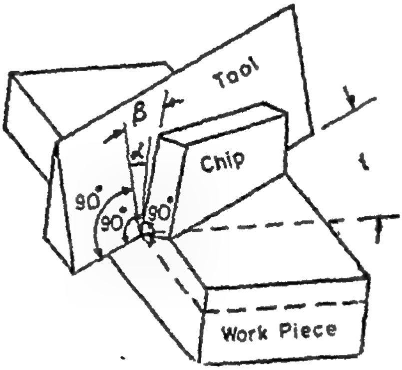


Fig. 2.03 Oblique Cutting System

The Oblique cutting system differs from the Orthogonal Cutting system in so many ways. Its salient features are ;

(*i*) the cutting edge is inclined at an angle '*i*' with the normal to the velocity V_c. The angle '*i*' is known as inclination angle.

(*ii*) The cutting edge may or may not clear the width of the workpiece.

(*iii*) The chip flows on the tool face making an angle β with the normal on the cutting edge. The angle being measured in the plane of the tool face.

(*iv*) Three components of the cutting forces are acting at the cutting edge. The components are mutually perpendicular.

(*v*) The tool may or may not generate a surface parallel to workface.

(*vi*) The maximum chip thickness may not occur at the middle.

(*v*) Frequently, more than one cutting edges are in action.

2.04 CHIP FORMATION

Every machining operation involves the formation of chips, the nature of which differs from operation to operation. The form and dimensions of such a chip from a certain process throw considerable light on the nature and quality of the process. The first light on the formation of chips during metal machining was thrown by Thimme from Russia who suggested that the basic mechanism of chip formation is by shear deformation. Since then, extensive studies have been made on chip formation by V. Piispanen, Ernst, Merchant, and Loladze. Ernst had even made a practical attempt by taking motion pictures through a microscope showing the formation of the chips. Accordingly, he had classified the chips into three groups and represented each group by a type number :

Type I—Discontinuous Chips (fig. 2.04)

Type II—Continuous Chips (fig. 2·05)

Type III—Continuous Chips with built up edge (Fig. 2.06)

Discontinuous Chips : The chips are small individual segments which may adhere loosely to each other and form length. The studies by Field and Merchant have revealed that segments are regularly formed due to the rupture of the metal ahead of the tool. The rupture of metal takes place when the metal directly above the cutting edge has

compressed to such an extent that the deformed metal starts sliding along the face and the magnitude of compression force reaches the

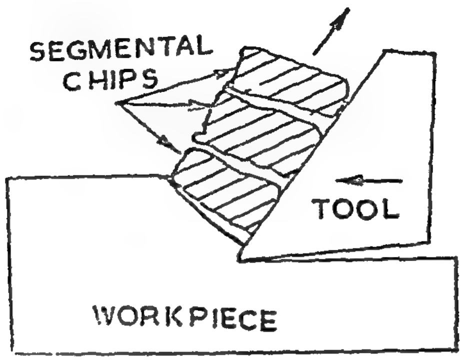


Fig. 2.04 Discontinuous Chips (Type 1)

fracture limit of the metal. The factors responsible for the development of discontinuous chips are :

1. Brittle and nonductile metals (Cast Iron, Brass castings, Berellium, Titanium etc.),
2. Low cutting speed and
3. Small rake angle in the cutting tool.

Since the chips are smaller, their handling becomes easier and they may be easily disposed off. Shorter chips will further impart good finish on the work surface since they do not interfere with the work surface.

Continuous Chips : Such chips are in the form of long coils having the same thickness throughout. The chips are produced due to the plastic deformation of the metal without rupture. Continuous chip without built-up edge is difficult to obt-

ain at normal cutting speeds. However, they can be had at very high speeds when the surface finish, and tool life improves and the power

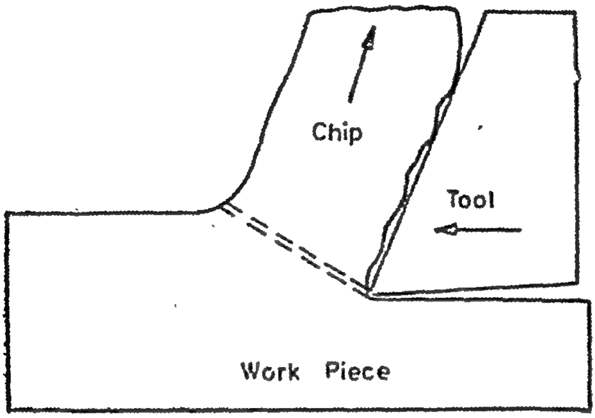


Fig. 2.05 Continuous Chips (Type II)

consumption reduces. The factors responsible for continuous chips are :

1. Ductile material,
2. High cutting speed,
3. Large rake angle,
4. Sharp cutting edge,
5. Efficient cutting fluids, and
6. Tool material giving low friction between tool face and chips.

Continuous Chips with B.U.E. Such chips also appear in the form of long coil but they are not as smooth a type II (fig. 2.06). On closely observing the cutting edge of the tool a small lump of metal welded to the chip tool contact area can be located at zone 1. This kind of welding is due to high pressure at the cutting edge. The lump of metal is known as **built-up edge.**

The built-up edge grows gradually at the cutting edge. When its growth is sufficiently large, it collapses, A part of it escapes with the chips in the form of very thin flakes (2) adhering underneath the escaping chips. Another part (3) of it gets embeded on the finished

from the shop pipe line to the cylinder where it actuates the piston having a road linked to the clamp through a inter-mediate device like toggle, rack and pinion or some form of lever. The cylinders may be single acting or double acting. Further these cylinders or the total unit is easily built up from the components. The components are manufactured as standard units by some firms. If it is desired to change the length of stroke the cylinders are available in various lengths and only the cylinder and studs are changed keepinging the piston, piston rod and end plates same. A built-up cylinder is shown

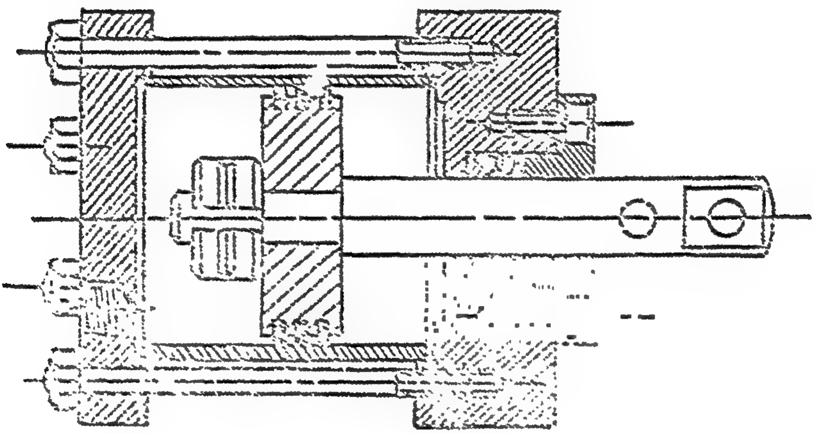


Fig. 14.54

in the figure 14.54. The cylinders are made of steel tubes or non-ferrous materials and end plates of cast iron. The piston is of either aluminium alloy or mild steel. The two washerd may be of leather or of moulded composition. It is found that leather although much used is not ideal for this work as it tends to harden and become brittle in use. The metal washer between two leathers is formed to suit the radius on the leathers. The gland where the piston rod passes through the top cover is of the same materials as the piston packings. It is recommended that all metal parts of the built up device other than those of non-ferrous metal which come in contact with compressed air should be cadmium plated as due to the unavoid-able moisture in the air supply the parts may rust badly. Single acting piston devices must be provided with springs to return the piston to its initial position and to release the workpiece. Uses of a piston to

its initial position and to released workpiece. Use of a piston device for actuating the clamping system is shown in Fig. 14.53.

Diaphragm Devices :

They have a cast iron housing between the halves of which a diaphragm of rubberised fabric or corrugated sheet metal is clamped. From one side the steel disc linked to a clamp actuating rod is held against diaphragm by the spring pressure. Compressed air enters the recess behind the diaphragm which is forced towards the disc and rod. This compresses the spring and actuates the rod. When air is released, rod is returned to its initial position by the spring pressure. Diaphragm devices have some advantages over piston devices in that they are 2. Simple and cheaper Smaller in size. provide longer service due to the absence of friction surfaces. However their small effective stroke is a disadvantage. (fig. 14.54a)

Apart from the built up cylinder of the piston devices or diaphragm device a complete pneumatic equipment includes the following items :—

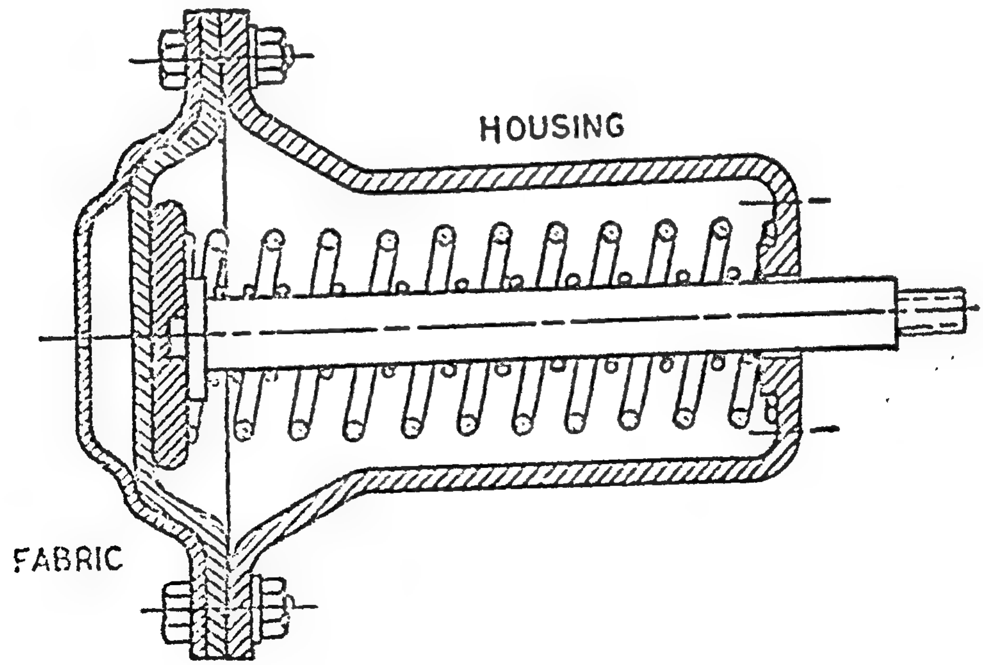


Fig. 14.54a

1. Stop valve for isolating the equipment.
2. Reducing valve to regulate the pressure.
3. Dial pressure gauge to check pressure in the line.
4. Lubricator.
5. Control valve for the operator, to be worked by hand or foot.

Hydraulic devices :

Sometimes considerable forces are required for clamping, such as in multiple clamping devices. The pressure available in the shop line being about 5—10 kg/cm^2 the internal diameter of the air cylinder will be quite large for obtaining higher forces. In such cases hydrualic devices will be more compact as almost any pressure up to 30—60 kg/cm^2 is always, available from independent commercial pump units. Apart from compactness of size hydraulic power offers two more advantages over pneumatic devices :—

1. The working cylinders are self lubricated and there is no problem of water condensation found in pneumatic systems.
2. The virtual incompressibility of the working fluid ensures positive action of the working parts of the mechanism employed.

A hydraulic device assembly consists of cold drawn seamless steel tubing for cylinder barrel. End plates are made of steel. In cylinder barrels and plates are available in various bore diameters. The length of a barrel can also be changed to change the stroke desired. Six silver steel studs clamp end plates and barrel together. The back plate is circular whereas the rod end plate is square with counter sunk holes at each corner for the screws which secure the cylinder assembly to its associated mechanism. Piston is made of

cast iron and the hardened steel piston rod slides through a phospher bronze gland which retains the multiple packing rings.

As already mentioned the hydraulic devices should be self sustaining. Clamping should be by means of pulling action of the hydraulic piston so that greater force is available for unclamping due to greater area of the piston on the other side of the rod. (fig. 14.55)

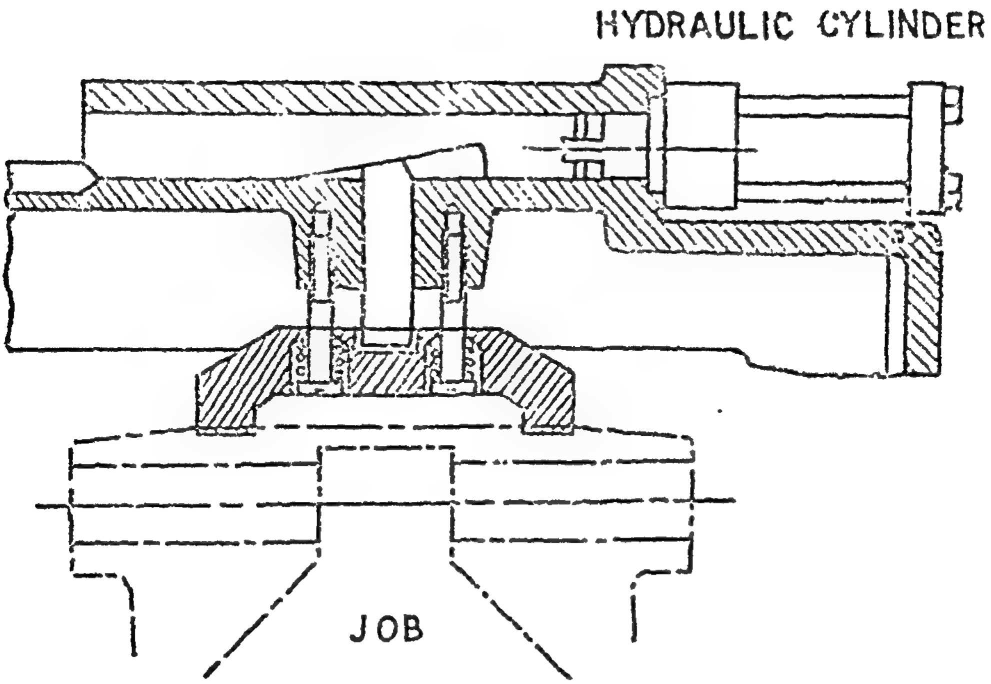


Fig. 14.55

Hydro pneumatic Devices :

In the hydraulic devices due to the high oil pressure there is always the danger of leakage through joints. Therefore a combition of pneumatic and hydraulic principles is applied to avoid movement of oil through pipes having joints. Devices utilising this principle are called hydro-pneumatic devices. The incompressible fluid remains in the hydraulic cylinder and acts as a media for transmitting pressure. Compressed air from the shop pipe line enters a pneumatic cylinder. The rod of the piston of the pneumatic cylinder-acts as a piston for a small bore cylinder filled with oil. This oil actuates the hydraulic piston which is of larger diameter than the rod of the air operated piston. A large force is thus develope

the rod of the hydraulic piston. Only disadvantage of the hydro-pneumatic device is the comparatively small stroke of the hydraulic piston since the gain in force is due to the loss in travel. (fig. 14.56)

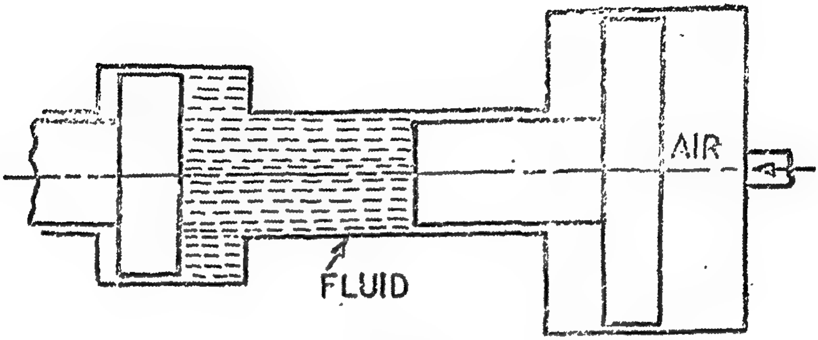


Fig. 14.56

Indexing Devices

If a component has many equally spaced holes to be drilled radially through the periphery of a flange, best means of drilling these holes would be an indexing jig which can bring the hole position under the drill each time it is indexed. Again if several surface are to be milled such as hexagonal nut or bolt head the fixture will have to be indexed by 60° each time to reorientate the job with respect to the cutters. Such a fixture will be called indexing fixture. Both indexing jigs and indexing fixtures must incorporate an indexing device. Milling machine index heads are most accurate indexing devices but they are costly equipment and if used for mass production will soon loose accuracy under the drilling and milling forces involved in operations. Thus other simple indexing devices for the particular operations in view are designed and incorporated in indexing jigs or fixtures. If dimensional accuracy is important, even the simple indexing devices added to jigs or fixture become costly affair.

Indexing is mainly of two types (1) Indexing to obtain complete or partial rotation of the component (2) Indexing to obtain a sliding movement of the component usually in one plane. Rotary indexing is required for drilling, milling or surface grinding operations. Where as other type is required for production lathes and

external grinding machines. A jig or fixture may be a two station, three or four station depending upon the number of indexing positions.

Principles enunciated earlier apply to jigs and fixtures using indexing devices also, however a few additional factors need also to be considered here. They are,

1. The workpiece should be positively located and clamped on the fixture independently of the index mechanism
2. The indexing device should be both rapid in action and positive in location.
3. Care should be taken to prevent swarf affecting the accuracy or functioning of the indexing device.

A few indexing devices that can be incorporated easily are as follows :

1. Spring loaded device : Every time the index plate is moved the spring loaded ball engages the next groove in the index plate. The ball is of steel, hardened and ground. The compression spring which is forcing the ball on the indexplate indent should be of sufficient force to have accurate indexing. Even then the method though cheap is not accurate one as spring becomes loose and positive action is hampered. (fig. 14.57).

2. Device using an indexing pin : The index plate here has number of holes depending upon the stations to be indexed. Every time the plate is to be indexed, the indexing pin retained in the fixed member is pulled back, the plate is moved until the pin engages the

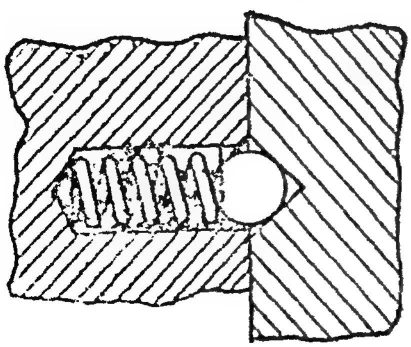


Fig. 14.57

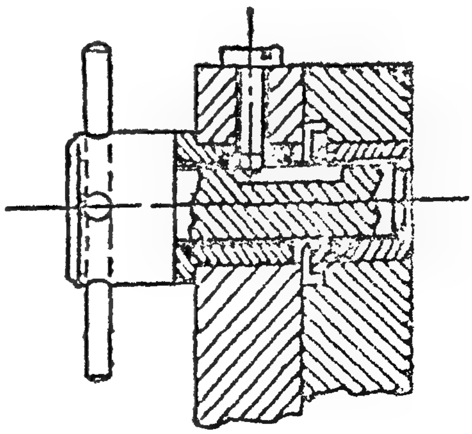
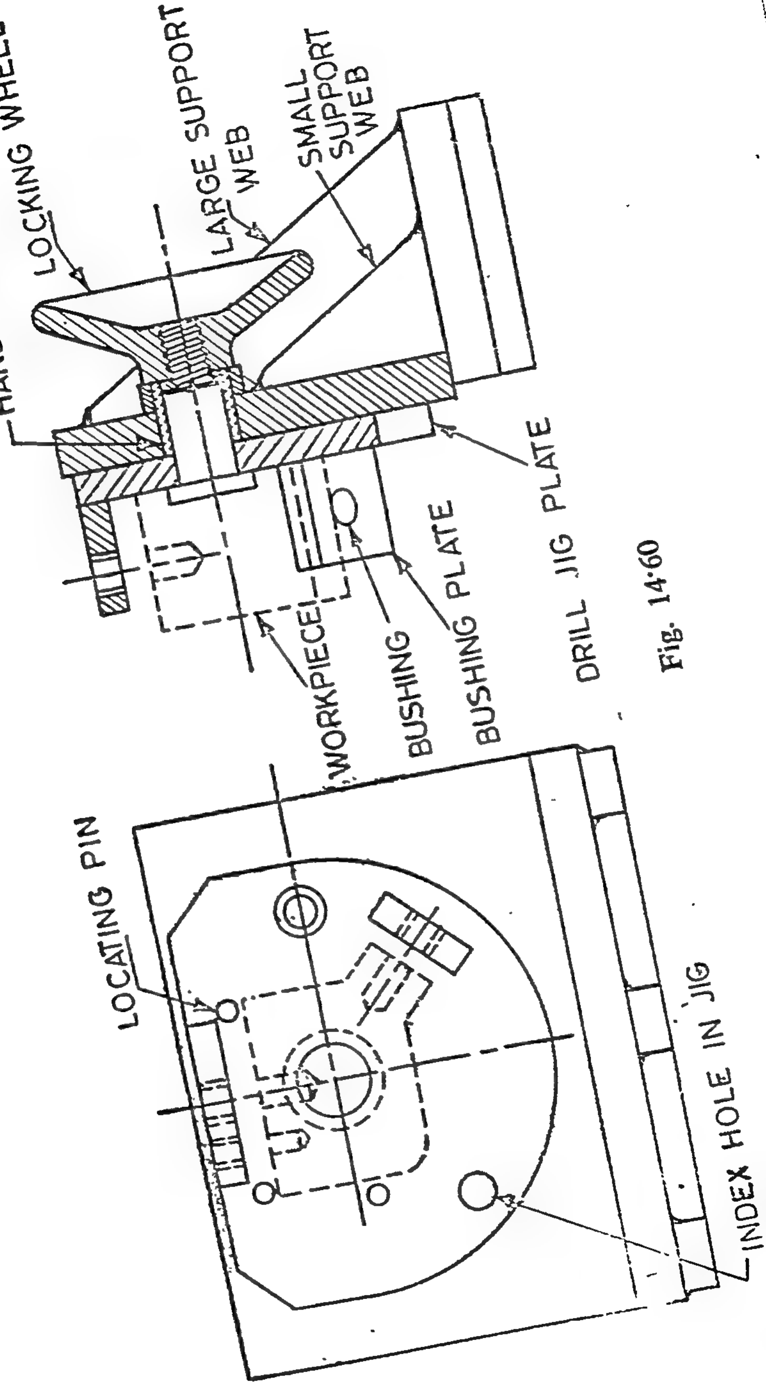


Fig. 14.57a



DRILL JIG PLATE

Fig. 14·60

Jig feet :—When castings are used the feet are cast integral with the body. If the feet are to be added afterwards then they are of steel and are hardened and finish ground on assembly.

Jig bushes : In terms of the maximum diameter the materials far drill bushes may be as follows :—

up to 15 mm outside dia meter	Silver steel
15—30 mm O.D.	Cast steel
above 30 mm O.D.	Case hardened mild steel.

The bore of a bush is generally ground and lapped to give a fine running fit with the tool with which it is to be used. A finish between 100 and 500 micron may be obtained without difficulty. Such a finish adds appreciably to the working life of the bush. bushes may be plated with hard chrome to prolong their lives. Fixed bushes are sometimes made from hard metal or cemented carbides. These are expensive because of difficulties in producing them especially the bores. The working life of the bushes however is greatly prolonged, compared with metallic bushes especially for small bores.

Locating and clamping devices :—Most of the locating and clamping devices are made from steel but those components which come in contact with components, are hardened and working surfaces are ground. Silver steel is used for parts like dowel pins, bars for handles etc. Threads generally should be left soft.

Commercial Jig and Fixture components

Except for jig bushes, component parts for jigs and fixtures have not be standardised due to several difficulties. However important firms have prepared their own standards and made available to designers many components in standard forms. Details of these components are available from the catalogues of the commercial firms. Main items in these catalogues comprise of base plates, jig

plates, hand nuts, thumb nuts, clamping devices, studs, tenons, locators and jacks etc. Cost of these mass produced components is usually considerably less than the cost of their fabrication in the plant. Purchased components also reduce assembly labour costs because they are designed for ease of assembly.

Universal jigs discussed earlier are also available commercially and can be transformed into useful jigs by suitable additions. They thus serve as basic units for jigs. By the use of universal jigs and other components which are commercially available jigs can be made considerably cheaper.

Economics of Jigs and Fixtures

The aim of all industrial activity in to serve society through cheaper goods so that they come within the reach of all men. Jigs and fixtures are utilised to increase production and reduce costs through saving in labour costs and other overheads. The money spent, to increase production, on the manufacture of aiding equipment is justified only if the final account shows a profit. Therefore before starting the design and construction of equipment its economic analysis must be worked out. Two very important items to be considered are the initial investment and the production volume. It is simple reasoning that if items to be produced are few a large investment will not be justified. The simple relationship between two items can be expressed in the following manner :—

If E=Production cost of component using present method.
S=Production cost of the same component after utilising special jig or fixture.
P=Cost of special equipment, jig or fixture.
N=Minimum number of components to justify the utilisation of the special equipment'

Then $N=\frac{\quad}{E-S}$ or $P=N(E-S)$

In the above treatment it is tried to recover the amount spent in one setting Moreover nothing has been charged in the shape of interest, insurance and taxes etc. which are always to be paid on the money borrowed or invested. Cost of equipment is increasing due

maintenance charges. All the money invested also can not be preciated over the first volume of production. It should be dis-buted over the life of the equipment. Thus to have exact analysis these factors should be taken into account. A complete analysis ll be as follows :—

Let N=Number of pieces manufactured or to be manufactured per year.

P=First cost of jig, fixture or other tooling equipment.

I=Annual rate of interest payable on investment, per cent.

R=Annual rate of repairs, percent

T=Annual rate of taxes and insurance charges per cent.

D=Annual rate of depreciation for the equipment, percent.

S=yearly eost of set up.

Total financial outlay due to the cost of equipment

$$=P(I+R+T+D)+S$$

Now again, a=saving in labor cost per unit.

t=percentage of overhead applied on labour saved.

V=yearly profit desired over fixed charges.

then total saving will$=Na+Nat$

$$=Na\ (1+t)$$

If no profit is desired

$$P(I+R+T+D)+S=Na(1+t)$$

However if profit V is desired

$$P(I+R+T+D)+S+V=Na(1+t) \qquad (I)$$

$$N=\frac{P(I+R+T+D)+S+V}{a(1+t)}$$

$$P=\frac{Na\ (1+t)-S-V}{I+R+T+D}$$

$$V=Na\ (1+t)-P\ (I+R+T+D)-S$$

If H=number of years required for recovering the investment s depreciation.

Then $D=\frac{I}{H}$

substituting $\frac{I}{H}$ in place of D in equation (I)

Number of years required for a fixture to pay for itself

will be

$$H=\frac{P}{Na(I+t)-P(I+T+M)-S}$$

Problem :

A fixture costing Rs. 500 is run thrice a year, on a milling machine. Each time the cost of set up is Rs. 2,000. The financial outlay on the money invested is interest at 6%, repairs 10% taxes and insurance 5%, depreciation 50%. Further a profit of 12% is desired on the investment. Estimate the quantity that must be provided in a year to recover the desired profit if labour saving per piece resulting from use of fixture is 10 paise and overhead saving is 50% of labour saved.

In the above problem :

$P=500$ Rs.

$I=6\%$ $R=10\%$ $T=6\%$, $D=50\%$

$S=3\times20=60$

$V=12\%$of $500=60,00$

$a=.1$ Rs.

$t=50\%$

Then

$$P(I+R+T+D)+S+V=Na(I+t)$$

$$N=\frac{P(I+R+T+D)+S+V}{a(I+t)}$$

$$=\frac{500(.06+.10+.06+.5)+60+60}{1(1+.5)}$$

$$=\frac{360+820}{.15}=\frac{480}{.15}$$

$$=3200 \text{ pieces.}$$

JIG AND FIXTURE DESIGN PROBLEMS

1. Design a drill jig for drilling the four 9.5 mm. dia holes in the square flange of the elbow shown in *Fig.* 14.61. The face of the square flange has been machined prior to this drilling operation.

2. Design a milling fixture for use when machining the elongated flange of the elbow shown in 14.61. This operation is done directly after drilling the four holes in the square flange.

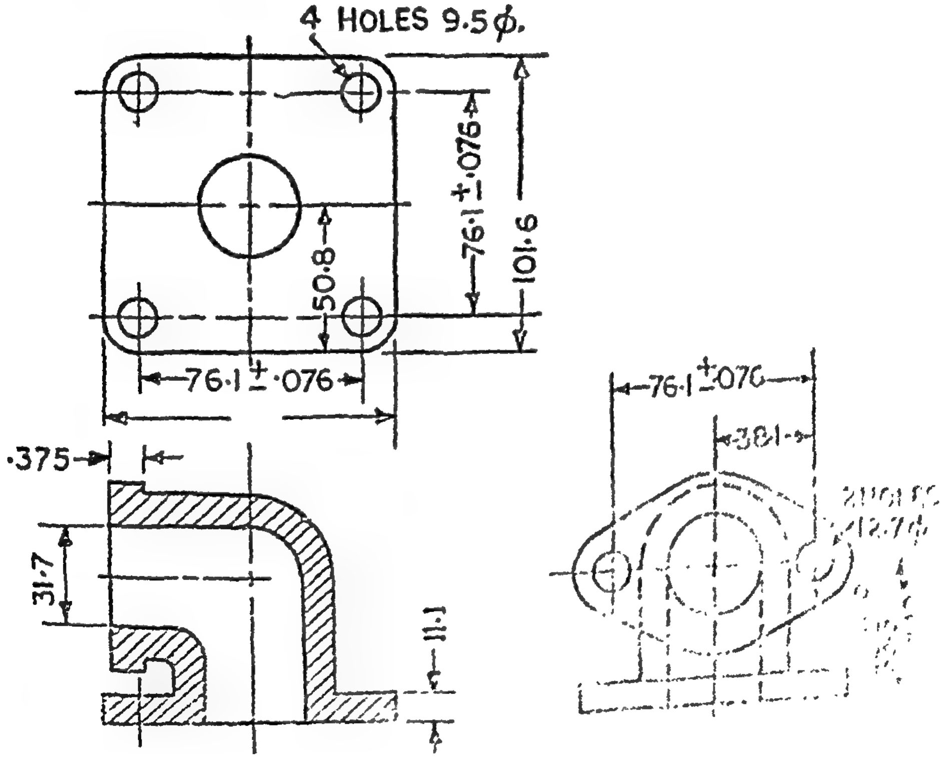


Fig. 14.61

3. Design a drill jig for use when drilling the two holes in the elongated flange of the elbow shown in Fig. 14.61. This operation is done directly after the flange is milled.

4. Design a drill jig for use when drilling the four holes in the flange of the housing shown in Fig. 14.62. The housing is complete except for these four holes.

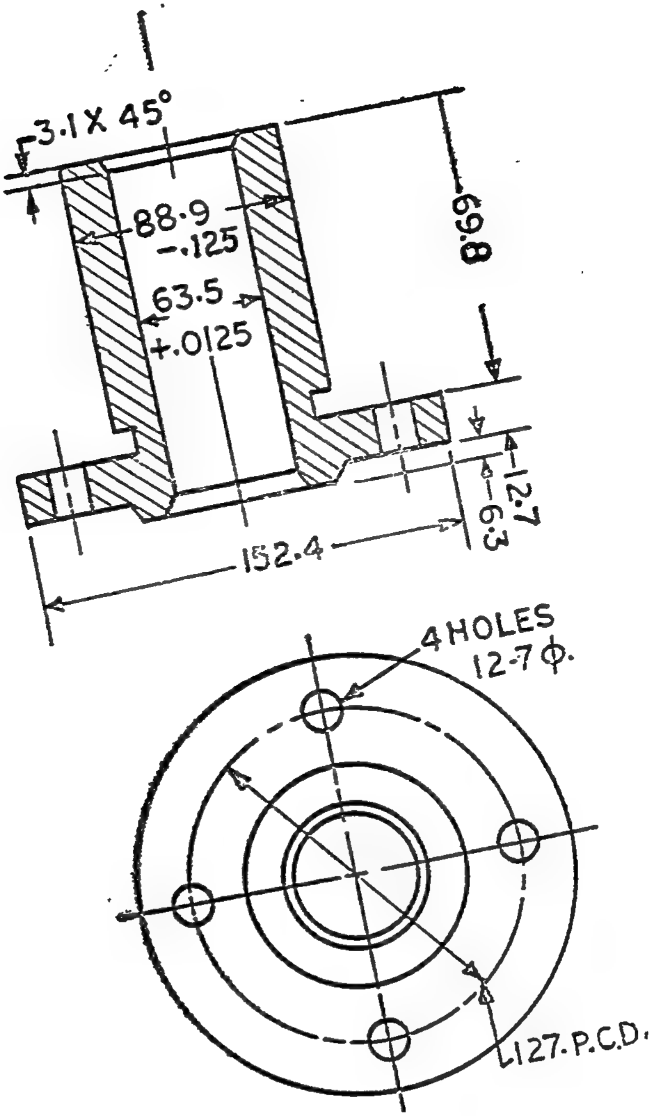


Fig. 14.62

5. Design a drill jig for use when drilling and cou the two holes in the flange of the connectio Fig. 14.63. The flange face and the bore of th been machined before this operation.

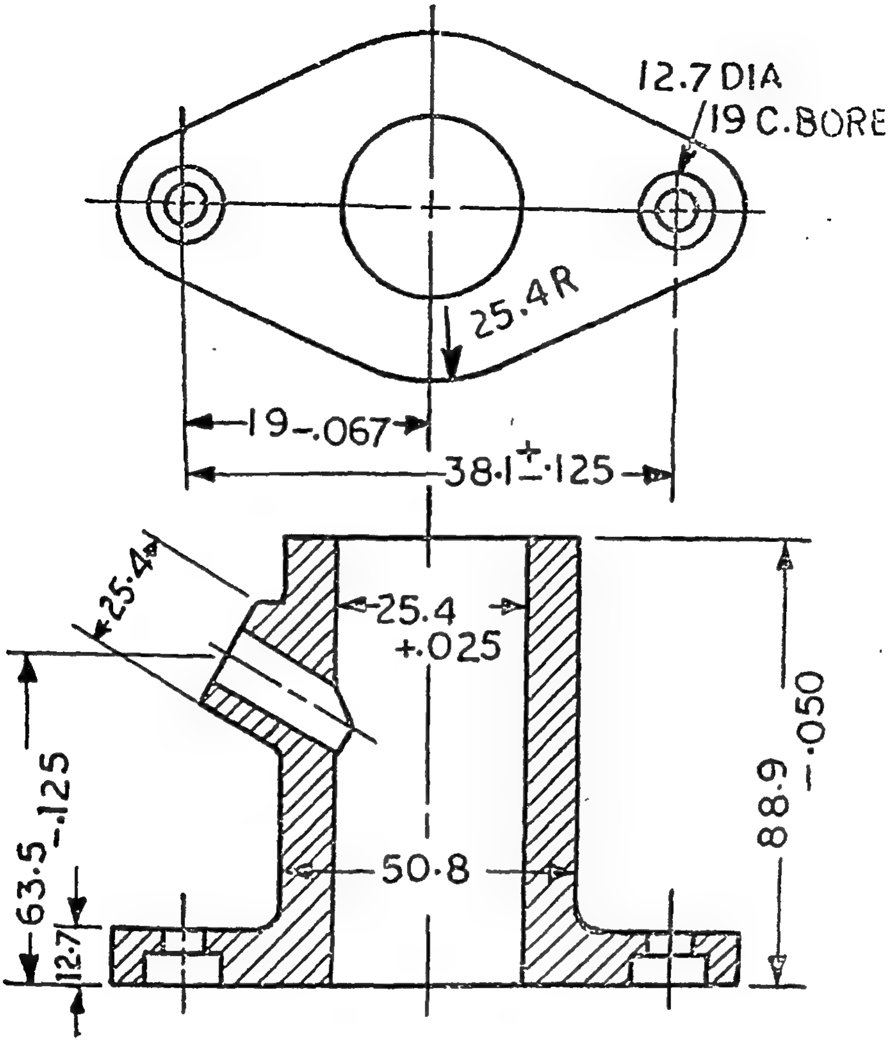


Fig. 14.63

6. Design a drill jig for drilling and spotfacing the 25.4 mm dia boss of the connection shown in Fig. 14.65. This is done after the flange is drilled.

7. Design a lathe fixture for a steel forging component to be machined all over and drilled after the first operation of drilling two 6 mm ϕ holes have been performed on a drilling machine Fig. 14.64.

8. Design an assembly fixture for riveting the component shown in Fig. 14.65. All holes have previously been drilled with the tolerance shown.

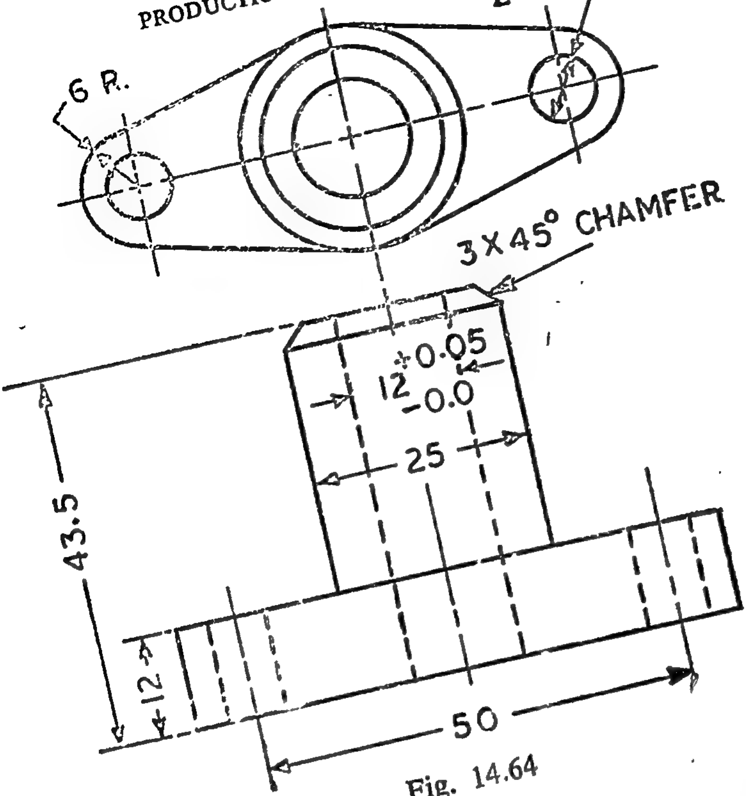


Fig. 14.64

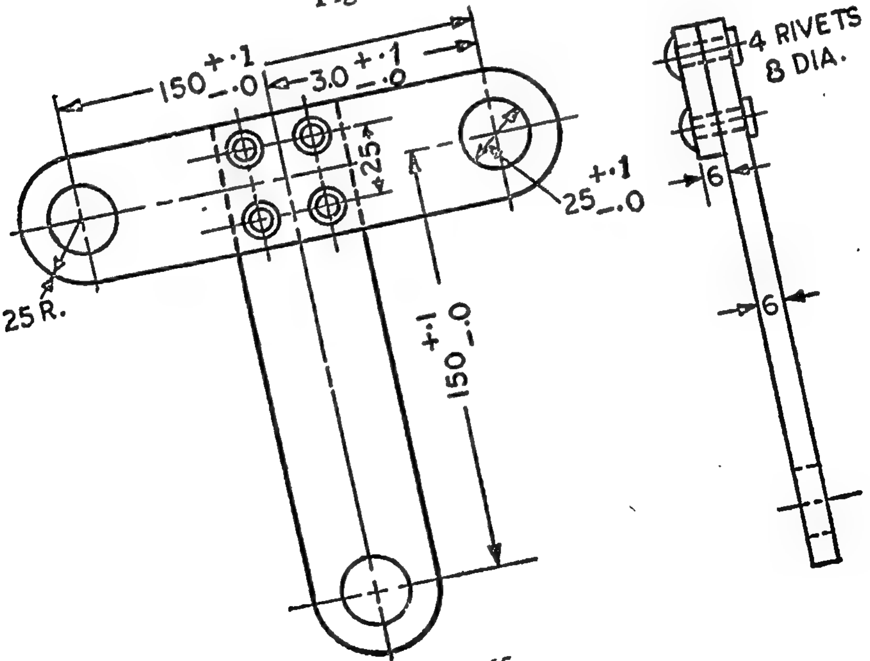


Fig. 14.65

QUIZ

1. Define a jig and a fixture, clearly establishing the difference between the two. How are jigs and fixtures useful to us ?
2. What are the fundamental principles of jig and fixture design ? Why a drill jig should have four legs, no more and no less.
3. Classify the drilling jigs in common use and make a sketch of each class. How does a template jig differ from a plate jig ?
4. What are the principles of location of drilling jigs ? Describe the degrees of freedom of work piece located in space. Draw a simple sketch to show the 3-2-1 locating principle.
5. List the locators commonly in use and explain each with the help of a sketch.
6. What is the function of a clamp in tool design ? State the requirements of a good clamping system.
7. With the help of sketches list various clamping devices in use.
8. What are the essential elements of a jig and a fixture for milling ? Explain the function of each element with the help of sketches. What are materials and modes of construction of each element ?
9. Classify the jig bushes used in drilling jigs. State where each kind of bush is used. Why must the inner liner of renewable bushings be clamped ?
10. What are the various types of milling fixture in use ? Explain each type with an appropriate sketch. What is the difference between an indexing fixture and a continuous rotary fixture ?
11. What is an indexing jig ? What are the various kinds of indexing devices commonly used ?

12. What is a centralizer ? How is it different from an equaliser ? Explain with the help of sketches.
13. What are the advantages of hydraulic and pneumatic clamping over mannual clamping ? Explain the hydraulic and air actuating devices in use. What are typical air and hydraulic pressures ?
14. Jigs and fixtures can be produced in many ways. Discuss the merits of each method with reference to the type of production.

CHAPTER XVI
PRESS TOOL DESIGN

Press working techniques utilizing economical tooling equipment design have greatly opened the way for mass production of articles such that most of the necessities like automobiles, refrigerators, office furniture and domestic ware made of stainless steel have come within the easy reach of common man. For any operation to be performed in presses for further fabrication the selection of a proper press is the first problem and the second problem is the design of a tool or die to be mounted on the press. The designer of the press tooling equipment is a man of experience and specifics the type of press, its specifications known to him, on which the tooling can be mounted. In fact the design of the press tool is accomplished keeping the specifications of press always in mind. To give an idea of the range of presses that can be harnessed for mass production with costly tooling equipment mounted on them, a brief knowledge of presses becomes very important here.

Classification of Presses :

Presses can be classified in the following manner :

1. By the power source.
2. By the intended purpose.
3. By method of transmitting power.
4. By frame design.
5. By number of independently moving rams.
6. By rated tonnage capacity.

Power Sources :

According to this classification the press may be named as Mannual Driven Press, Mechanical Press, Hydranlic Press, or Pneumatic Press.

Mannual driven presses are low capacity presses ranging from 1/2 ton to about 10 tons. The energy is supplied by human effort at the rim of a flywheel in the flyscrew press and at the end of a lever in the arbor press. In the flyscrew press the angle of the

press may be named as punching press, drawing press or coining press only.

Method of Transmitting Power :

In mechanical presses the power is derived from a motor driving a flywheel or gear and may be delivered to the ram by means of crank shaft, eccentric, cam, knuckle joint ; toggle joint, rack and pinion or power screw mechanism. In the manual driven press the power is transmitted either through a power screw as in fly press or rack and pinion as in arbor press.

Frame Design :

There is no limit to variety of frame styles and sizes in which presses are available. Presses are of vertical and inclinable design. Then they may be of double frame and single frame. Double frame presses may have a gap like the single frame or they may be open at the back. Both double and single frame presses may have an opening in the bed to permit work or scrap to drop through when dies of this type are employed. Single frame presses with gap are mostly called C frame presses also. Hydraulic forging presses consists of vertical pillars sometime two and sometimes 4 in number held at the bottom in a bottom plate and at the top by a crown plate which also supports the hydraulic cylinder. The ram is also guided in the vertical columns. Such a design permits good visibility and ready access to the tooling area from all four sides.

Open back inclined press (OBI) of the doble frame type ranging in capacity from 5 to 100 ton is most commonly used in the shops. Whereas for capacities from 5 to 20 tons C type single frame is quite common.

Number of Rams :

Depending upon the number of rams the press may be a single action press, double action press or triple action press. Single action press has one ram only actuated by any of the means mentioned earlier. It is the most popular type of press for most stamping operations and can use both compound and progressive dies. Double acting press has two rams, one operating inside the other. Such a press is useful for combination dies where in deep drawing it is necessary to hold the blank with an outer pressure pad while the punch is drawing the desired shape down into the die. The outer

slide in a double action press can be used for this blank holding function and will remain stationary in its lowest position until the inner and working ram has moved past lower dead centre and begins to ascend. Triple action presses are similar to double action presses but emoloy a third slide in the base of the press that moves up through the press bed to perform a supplementary operation. A typical use of this press may be for combination embossing blanking and drawing where the lower ram actuates the embossing die.

Capacity of the Press :

The rated tonnage capacity of a press indicates the maximum pressure which the press is designed to safely accommodate. Apart from naming the press by various other rams, the capacity of the press must be linked with the name so that a job requiring that much capacity and no more should be assigned to it. Sometimes when a higher capacity press is not available for a job the lower capacity press can be suitably used by properly modifying the design of the dies.

So a press can be conveniently classified by any one classification or by a combination of several classifications *viz.* a fifty ton open back inclined mechanical press. A 50 ton hydraulic forging press. A 50 ton triple action drawing press etc.

Major Components of A Mechanical Press :

1. A rectangular bed which is part of the frame and is generally open in its centre to allow scrap or blank to fall down. The bed supports the bolster plate. The whole bed along with the frame can be inclined by swiveling on the bottom frame. Bed along with the frame is either of C.I, or it is welded structure these days.

2. A bolster plate : It is a flat steel plate from 2 to 5 inch thick, upon which press tools and accessories are mounted. In shop practice this plate is affixed to the press bed and is seldom changed even though new jobs are successively set up on the press. The bolster plate may or may not have a centre opening leading through the press bed. The bolster plate often is provided with T slots running from front to back.

3. A ram or slide that moves through its stroke, a distance depending upon the size and design of a press. The

position of the ram but not its stroke can be adjusted. However there are presses with a special design where strokes can also be changed.

4. **A knock out** : It is a mechanism operating on the upstroke of a press which ejects work pieces or blanks from a press tool.

5. **A cushion** is a press accessory located beneath or within a bolster for producing an upward motion and force, it is actuated by air oil, rubber or a combination thereof.

Shut Height :

It is the important dimension of a press. The tooling equipment designer must know the shut height of the press because the punch and die alongwith punch holder and die holder are to be designed for a particular shut height of the press available. Shut height, determines the length of the punch and thicknesses to be allowed to die holder, punch holder, etc.

Shut height is the distance from the top of the bed or (bolster) to the bottom of the slide with its stroke down and adjustment up.

Selecting the proper press :

In selection of the proper size and style of press for a given kind of work the following points are to be considered :

1. The size and type of die required.
2. The amount of stroke necessary.
3. The pressure required for doing the work.
4. The distance above the bottom of the stroke where the pressure first occurs.
5. Any additional pressure required due to attachments such as the blank holder, ironing, wrinkles, or stretching the material in drawing work.
6. The method of feeding, the direction of feed and the size of the sheet blank, or work piece.

Components of a Die Assembly :

The press is a universal type of machine tool which is used for many different operations and jobs. Special tooling is designed

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to adopt the press to a specific job or operation. This tooling constitutes the die assembly or simply a press tool die. This assembly consists of two halves, one being mounted on the moving ram and the other bolted or clamped on the stationary press bed or bolster plate.

The assembly incorporates two main members, a male member and a female member. Male member is the punch and female member is the die block or simply a die. There are other components also in the die assembly to retain and fix the two main member in a fixed and a aligned position. Typical components of a cutting die assembly are shown in the figure 15·1. A simple description of each is also given.

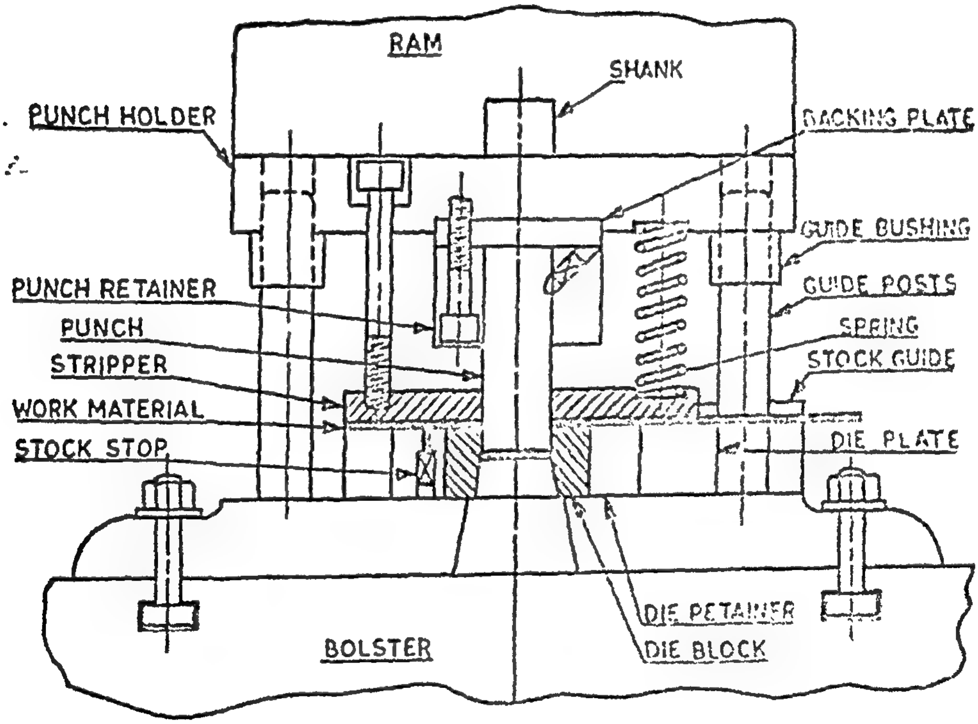

Fig. 15·1

The Punch :

It is the male member of the unit and is kept as small as possible consistent with required strength and rigidity. The punch is made of a hard, wear resistant metal and is finally ground to a pre-determined size providing just optimum clearance between the punch and the die.

CLASSIFICATION OF PRESSES

1	2	3	4	5	6
Capacity	Power Source	Transmission method	No. of rams	Frame Design	Purpose
0.5 tons	Manual	Rack pinion (Arbor Press) Power Screw (Fly Press)	Single action	Single frame (Open bed type, gap type). Vertical double frame (gap type, open back type, open bed types).	Assembling Fitting
5.100 tons	Mechanical	Crank Cam Eccentric Joint Friction Power screw Rack & Pinion	Single action Double action Triple action	Vertical (Single frame) Open bed type, gap type, Inclined (Double frame) Open bed type, gap type, open back type.	Blanking Drawing Embossing Trimming
Above 103 tons	Hydraulic	Hydraulic cylinder	Single action	Vertical column type	Stamping Forging Drawing Forming Assembly

to adopt the press to a specific job or operation. This tooling constitutes the die assembly or simply a press tool die. This assembly consists of two halves, one being mounted on the moving ram and the other bolted or clamped on the stationary press bed or bolster plate.

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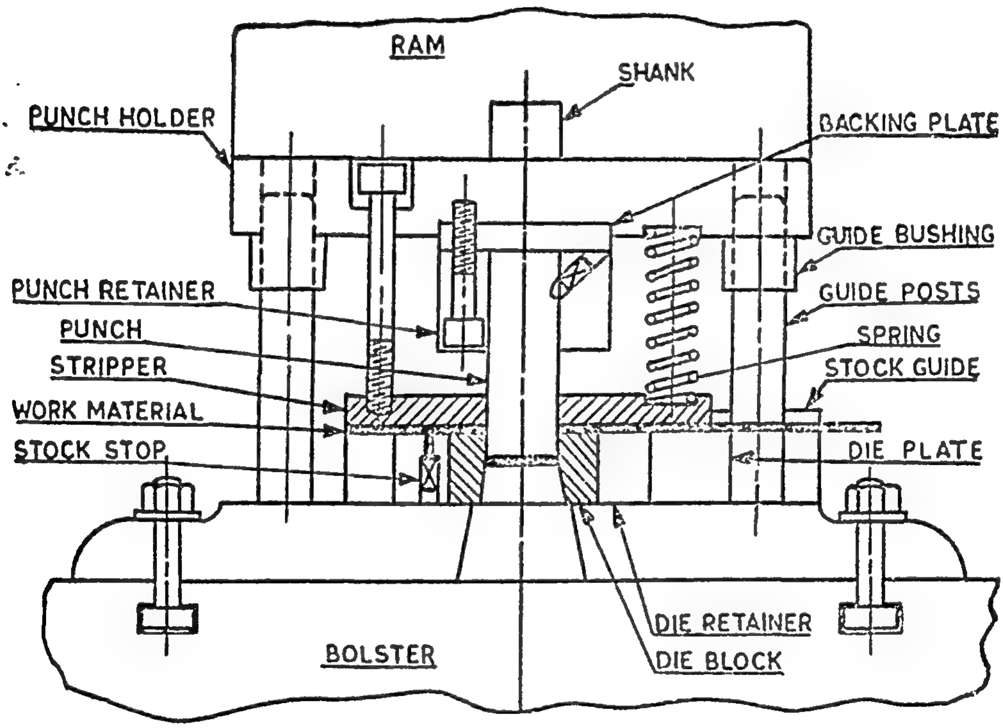


Fig. 15·1

The Punch :

It is the male member of the unit and is kept as small as possible consistent with required strength and rigidity. The punch is made of a hard, wear resistant metal and is finally ground to a pre-determined size providing just optimum clearance between the punch and the die.

The Punch Retainer or Punch Plate :

It fits closely over the body of the punch and holds it in the proper relative position. The retainer in turn is bolted to the punch holder.

The Punch Holder :

It provides a wide flat surface which faces against the lower end of the press ram and is anchored to it with the help of shank which is an integral part of the punch holder. Shank exactly fits into the ram opening, to help in properly positioning and aligning the punch. The punch holder is made of cast steel.

Backing Plate :

Whenever the punch is headless, a hardend steel backing plate is introduced between the back of the punch and punch holder so that the intensity of pressure does not become excessive on the punch holder. Backing plate distributes the pressure over a wide area and intensity of pressure on the punch holder is reduced to avoid crushing.

Die Block :

It is the female working member and is kept as small as possible consistent with required strength. It is also made of a hard, wear resistant metal and is finish ground to predetermined size and tolerance.

The Die Retainer :

Just like the punch retainer, the die retainer also holds the die block at proper position with respect to punch. The retainer is mounted on the die shoe or holder. In certain designs die shoe itself serves as a retainer for the die block. The die block is then mounted directly on to die shoe.

Die Shoe :

Die shoe assembly consisting of die block and die shoe is, in turn bolted or clamped to the bolster plate.

Guide Posts and Bushings :

The punch and die members once properly located and aligned, are held in alignment by means of guide posts and bushings which resist movement or deflection of die members as operating pressures

increase. Guide posts and bushings are part of the commercially available punch and die holders.

Stripper or Stripper Plate :

When the punch has completed its downward movement and starts returning, the scrap strip tries to go up along with it. The stripper plate prevents this upward movement of the scrap strip and frees the punch of this for next stroke. The strippers are of many designs and will be dealt with later on.

Stock Stops and Stock Guides :

Fixed type of strippers sometimes are used to guide the stock also where as stock stops locate the work material at a suitable position in relation to previously blanked surface in preparation to the next downward movement of the punch. Stock stops like strippers are always available in a variety of designs and will be dealt with later.

CLASSIFICATION OF DIES

There are dies which are designed to perform only one operation with each stroke of the ram. They are of simple design. But if several operations are to be completed in one stroke of the ram or rams (in case of double action presses) then design becomes a little complicated. Dies of the first class are single operation dies and dies of the second class are called multi-operation dies.

- Single action Press
  - Single operation
    - Cutting
    - forming
  - Multi op.
    - Compound
    - progressive
    - Combination
- Double action press
  - Single op.
    - Cutting
    - Forming
  - Multiple op.
    - Compound
    - Progressive
    - Combination

Single operation dies can be further classified into two main classes. They are :

1. **Cutting dies :** They are used to prepare blanks etc., for further operations like bending, forming and drawing by utilising the cutting or shearing action. Cutting dies can be further defined by the

specific nature of the operation ; they are called upon to perform. Among the more common types in the group are blanking dies, piercing dies, perforating dies, notching dies, trimming dies, shaving dies etc.

2. **Forming Dies :** These dies change the appearance of the blank without removing any stock. They add third dimension detail. In this group are the bending, curling, forming and drawing dies.

Multi operation dies are often used to bring two or more cutting and forming operations together into one work cycle. However each operation usually requires a separate punch and die unit which is subject to the same general considerations as a one operation die that performs the same function. The principal types of multiple-operation dies are the compound, combination and progressive dies.

Compound dies :

They perform two or more cutting operations such as blanking and piercing. They are usually single action dies where all the operations are completed with one ram stroke at the same station.

Combination Dies :

They combine cutting with forming or drawing operation. Blank is thus prepared in the die itself. They are usually multiple action dies with one operation succeeding another. This is achieved entirely within the die assembly by use of cam actuated punch and die members or by designing the die for use on a double action press which has two independant rams or slides one moving inside of another.

Progressive Dies :

Work piece in progessive dies travels from one station to another, with separate operations being performed at each station. Usually the work piece is retained in the stock until it reaches the final station which cuts off the finished piece. All stations work simultaneously but at different points along the work strip which advances one station at each stroke of the ram. Thus one completed blank is produced with each stroke. Progressive dies generally include blanking and piercing operations but complicated progressive dies can do the operations of bending, forming, curling and beading also.

Some of the other dies which do not fall within the above classification are extrusion dies, coining dies, swaging dies, upsetting dies and embossing dies.

Cutting action in a Die.

Blanking and piercing operations are performed to prepare the stock for further processing in forming diea for bending, forming and drawing operations. In blanking operations, the piece to be used or further processed is punched from the strip stock where as in piercing operation a portion is further punched from the piece to be used or further processed. The portion so removed is the scrap. Both blanking and piercing operations are cutting operations performed in cutting die components.

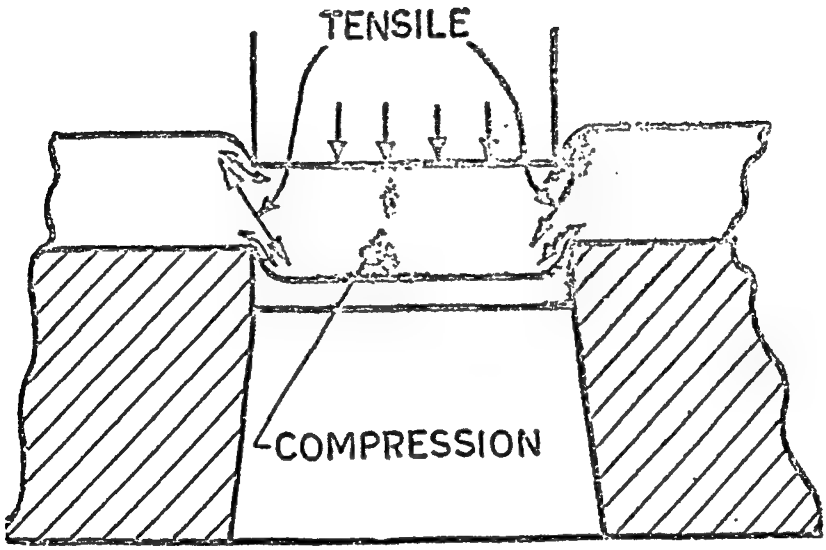


Fig. 15·2

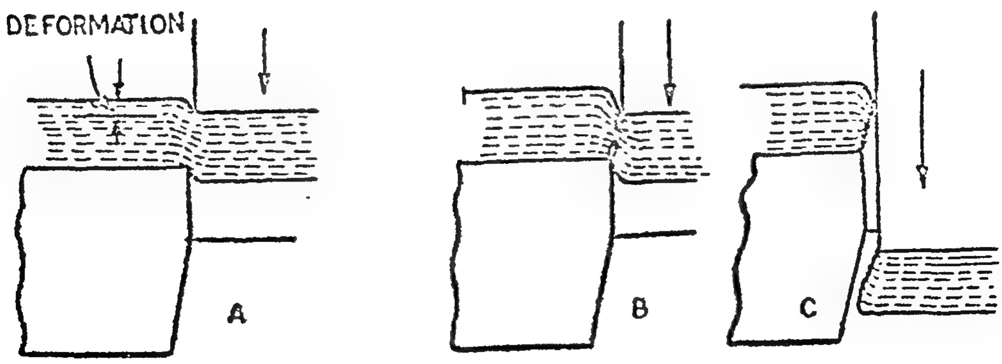


Fig. 15.3

The cutting of metal between die components is a shearing process in which the metal is stressed in shear between two cutting edges to the point of fracture or beyond its ultimate strength. The metal is subjected to both tensile and compressive stresses. Stretching beyond the elastic limit occurs. Then there is plastic deformation and reduction in area. Finally fracturing starts through cleavage planes in the reduced area and becomes complete. As in tensile test of a long specimen of mild steel the fracture takes place along the plane of maximum shear (figs. 15·2 and 15·3.)

Punch and Die Clearance :

The clearance is the space between the mating members of a die set. For cutting contour surfaces it is the difference between the punch and die diameters. The amount of clearance between the cutting edges of a punch and die block is highly important to good press work. Both excessive clearance and too small a clearance are not desirable due to reasons described below. A clearance that is neither excessive nor too small and produces a good blank is called the *optimum clearance*. Clearance between the punch and the die depends upon the hardness of the material to be cut and effects the following :

1. Characteristics of the sheared edge.
2. Percentage penetration.
3. Press exertion.
4. Tool life.
5. Burr height.

Characteristics of the sheared edge :

The fracturing of the piece from parent metal takes place in three stages. Fig. 15·4. In the first stage the punch draws the stock in a bend around its cutting edge till the elastic limit is reached. This action provides a radii adjacent to the die on the blank and adjacent to the punch on the stock. In the second stage the punch penetrates the stock to some depth, the material under the punch moves relatives to stock on the die and also relative to the die opening itself until no more deformation can take place and fracture just starts from the corners of punch on one side and corners of the

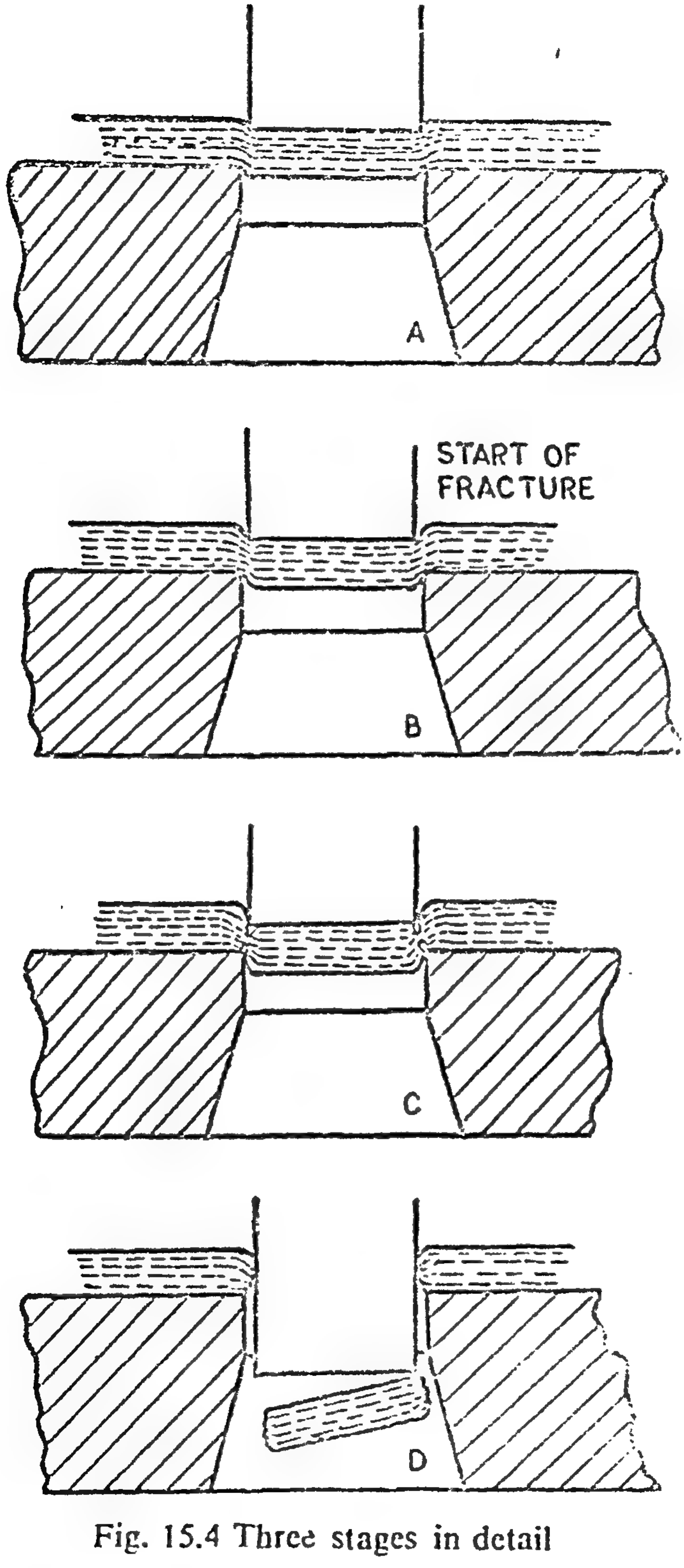


Fig. 15.4 Three stages in detail

die on the other side. This straight movement of the punch in second stage gives rise to a burnished surface both to the sheared

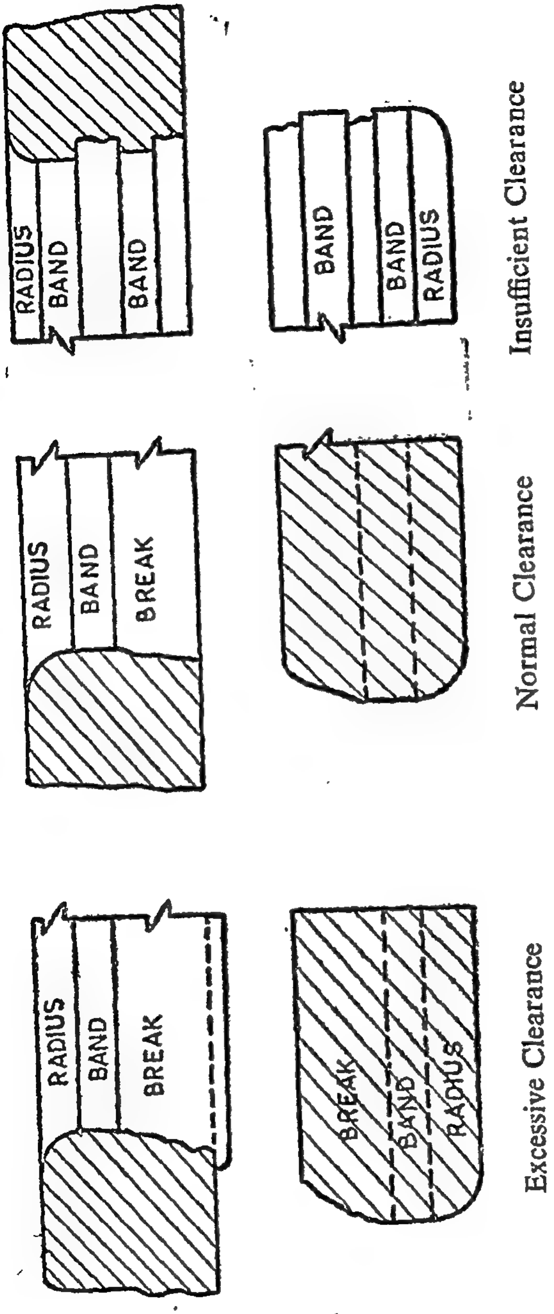


Fig. 15·5 Effect of clearance on sheared edge

piece and the stock, though at different positions. This burnished surface which imparts a bright polished finish along a proportionate section of the sheared edge determines the percentage penetration. In the third stage the fracture from one side meets the fracture from the other side all round the contour and fracture becomes complete. The fractured surface is not vertical but somewhat tapered in almost all shearing operations. So the process of shearing gives rise to a sheared edge that has three characteristics. *Fig. 15·05.*

1. A corner radius.
2. A clean burnished surface.
3. An rough, burred taper surface, dull grey in colour.

Excessive clearance causes a large radius to be formed at the corners along with burrs on the opposite corners, thus reducing the depth of the burnished band, whereas too small a clearance sometimes gives rise to, two such small bands in harder materials. Band depth is about one third of the thickness of the stock. Again excessive clearance results in a tapered cut edge.

Percentage Penetration : The depth of white polished band formed in the second stage of shearing action determines the percentage penetration which is ratio of this depth to original thickness of the stock expressed in hundreds. The percentage penetration is about 33% but it greatly depends upon three factors *i.e.*, clearance, hardness and thickness of the material to be punched. As the hardness of the material increases the material becomes more regid and punch can travel only a shallower depth before the fracture starts. Thickness of the stock also has a similar effect. The greater the thickness the more rigid the sheet becomes and lowers the percentage penetration. Thus if the material is hard and thick the clearance will have to increased accordingly but it should not become excessive also.

Press Exertion :

Too small clearances require excessive forces to shear the material. Apart from increasing clearances, shear angles on punches and dies reduce the shearing force required at the peak point. The shearing force is thus small but uniform over a large part of the stroke.

Tool Life :

Both punches and dies become blunt if the clearance is too small. They have to be ground after short runs and set again. Blunt edges require excessive force to punch the material. The burrs on the work become predominent. Blunt cutting edges also cause excessive radii on the opposite work surfaces. The fractured surfaces are rougher and may show many minute cracks which weaken the edges.

Burrs And Bowing Effects :

Too small a clearance blunts the tools and is the cause of burrs after sometime. Too excessive a clearance also causes burrs along with excessive radii. Bowing effect is increased with excessive clearance.

Summing up the bad effects of excessive clearance they are :—

1. Sheared edge taper is increased with large radius on one corner of the sheared edge and burr effect on the other.
2. Bowing effect is increased.

Too small a clearance has the following effects.

1. Force required to shear becomes excessive.
2. Tool life decreases.
3. Sides are smooth and vertical.

The aim of the tool designer therefore is to reach at a optimum value of the clearance avoiding the bad effects of the two. Optimum clearance should give smooth vertical sheared edges with minimum of bowing effect and maximum of tool life within regrinds. It is about 10% of the thickness of the material but varies with hardness. Hard materials require more clearance than soft materials. For the same thickness the harder the material, the more clearance to be allowed.

Optimum clearances for various materials are : steel about $7\frac{1}{2}\%$, brass 5%, Copper 4 to 5%, aluminium 10% and magnesium 2%.

Control of hole and blank sizes by clearance location :

If a blank is to be prepared of a given size, then make die to size and punch smaller by total clearance. If the hole to be made

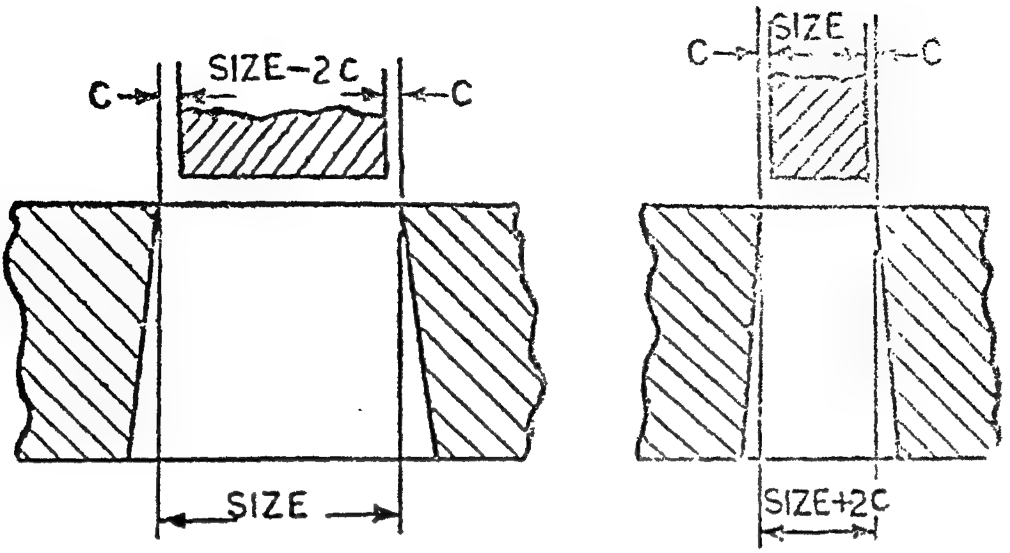
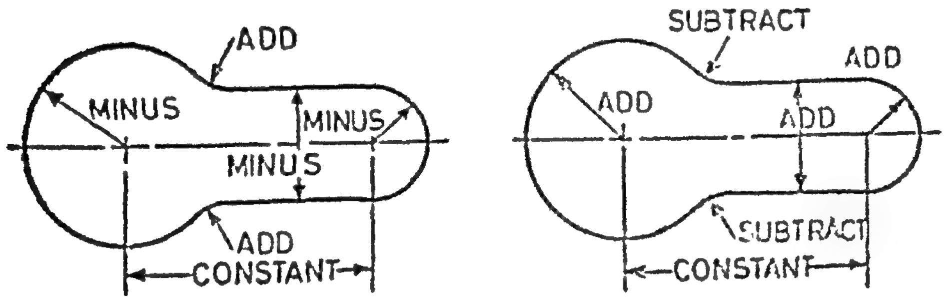


Fig. 15.6 Control of blank and hole sizes



Clearance on irregular shaped punch (blanking)

Clearance on irregular shaped die (piercing)

Fig. 15·07

is to be of exact size and inner portion called slug is to be scraped then make the punch to size and die larger by the amount of total clearance (Fig. 15·6.) The application of clearances on irregular shaped punches or dies is also shown in fig. 15·07.

Angular Clearance :

If the blank or the slug is to pass through the die in a blanking or piercing operation, the angular clearance is necessary in order to prevent the possibility of a blank or slug jamming in the passage. The angular clearance is usually ground from 1/4 to 1½ perside. The die is usually machined straight for 3 mm in order that the punch clearance will not be increased when the die is sharpened by grinding the face.

Cutting Forces :

The pressure required to shear the material in blanking and and shearing operations is given by the formulae.

$P = \pi D f_s t$ for round holes.

$P = L \times f_s \times t$ for other contours.

Where f_s is the shear strength of the material in kg/mm²
D is hold diameter in mm.
L is shear length or perimeter in mm.
t is material thickness in mm.
P, cutting force will be in kg.

The shearing strength to be used in the above can be found from tables.

Determination of cutting forces gives an idea of the capacity of the press to be selected. Press capacity must be higher than the cutting forces required to punch the material. Press bed is stressed by the cutting forces over a very short period of time. It is however desirable to reduce this instantaneous force and spread it over a larger portion of the ram stroke if the capacity of the press available is low. This can be achieved by providing a shear to the punch or die or stepping the punch lengths in case of progressive dies.

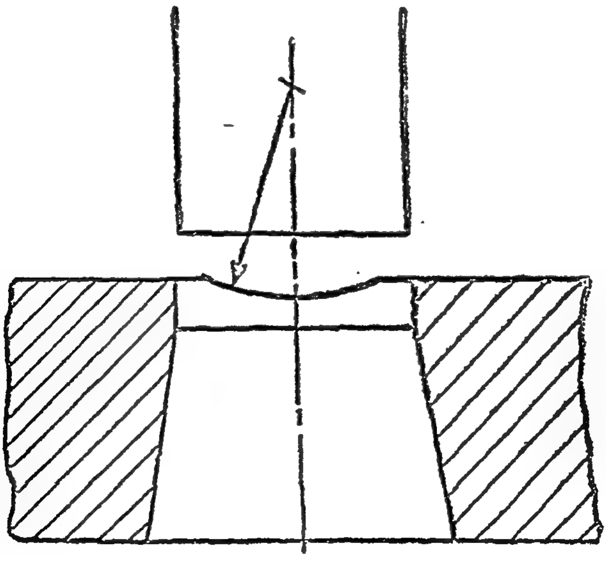


Fig. 15.08 (*a*)

Shear on Punches and Dies :

Inclining the cutting edge of either the punch or die block in relation to the cutting edge provides a *shear* to the punch or die. There are several ways of providing this shear. The more common methods of applying the shear are as follows Fig. 15·08.

1. Inclining the full cutting face of either punch or die block in relation to place of contact.

2. Inclining the cutting edge to each side of centre so as to permit cutting either from the centre outward or from the ends towards the centre.

3. Grinding a concavity along the cutting edge of the die or grinding several waves of concave surfaces in case of large heavy blanking surfaces.

4. Providing a slow helix or spiral along opposite sides of a circular punch.

Shear should not be provided on punch if the slug is the desired piece because a shear on the punch will distort the slug. In that case shear should be provided on the die. Double action shear as in Fig. 15·08 b is preferable as it maintains symmetry and prevents set up

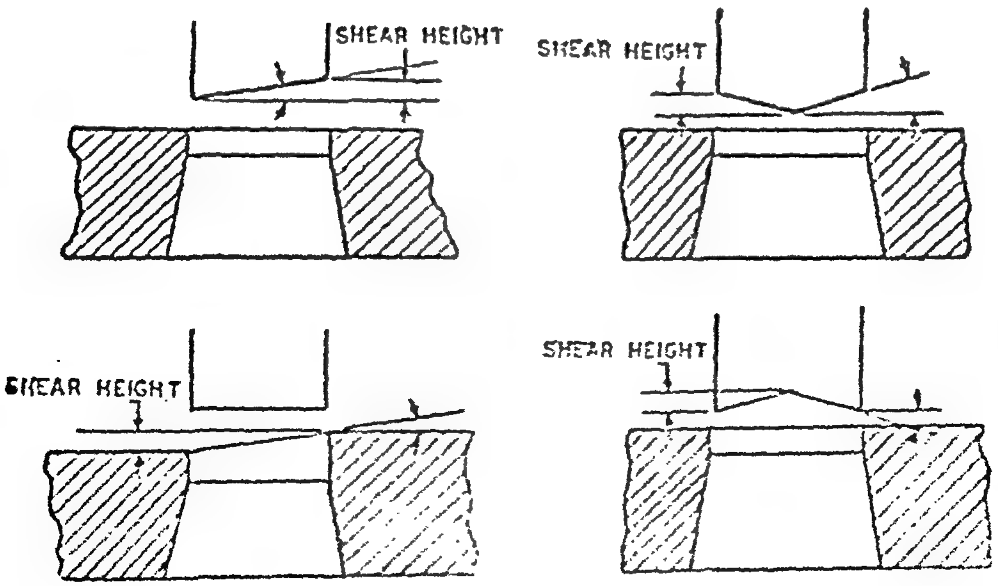


Fig. 15·08 b

of lateral forces. The shear angle chosen should provide a change in punch length of about $1\frac{1}{6}$ times stock thickness.

Punch Press Energy :

The press selected may be satisfactory as regards the pressure requirements but an investigation of the available energy and power is also necessary. Energy to do the work of punching is obtained from the flywheel and power from the electric motor.

The energy required to punch the hole in kgm.

E=Pressure to shear multiplied by the distance through which the penetration takes place.

$=P \times t \times$ percentage penetration

where t is in metre.

Generally the pressure is minimum in the beginning, rises to maximum somewhere in the middle and once the fracture starts, it again comes down to zero. Hence work done or energy required is represented by the force distance tringle and is given by $\frac{1}{2}$ Pt also. where P is the maximum value of pressure or cutting force and t the thickness in metre. Work done is obtained in kgm. This much of energy must be supplied by the flywheel of the press selected.

$$E=I(w_1^2-w_2^2)$$

Where I=moment of enertia of the flywheel.

w_1=speed in radians/sec in the beginning.

w_2=minimum speed in radians/sec. allowed.

Allowable speed variation in punch press is about 20%. If the energy to blank is E kgm per stroke and press can work at N number of strokes per minute.

$$HP \text{ required}=\frac{E \times N}{4500} \text{ hp.}$$

Centre of Pressure :

In case of irregular shaped punch, the summation of irrigular shearing forces on one side of the centre of ram, may greatly exceed the forces on the other side. This results in a bending moment in the press ram and undesirable deflection and mis-alignment. It is therefore necessary in case of irregular shaped punches to find out the exact centre of pressure and layout [the punch position on the punch holder in such a way that centre of pressure and

centre of ram hole or centre line of shank are in the same straight line. Summation of shearing forces must be symmentrical about the centre of pressure. It is centre of gravity of the line i.e. the perimeter of the blank contour. It is not the centre of gravity of the area.

Method of Calculation of Centre of Pressure :

1. Draw an outline of the actual cutting edge as indicated in figure 8·9.

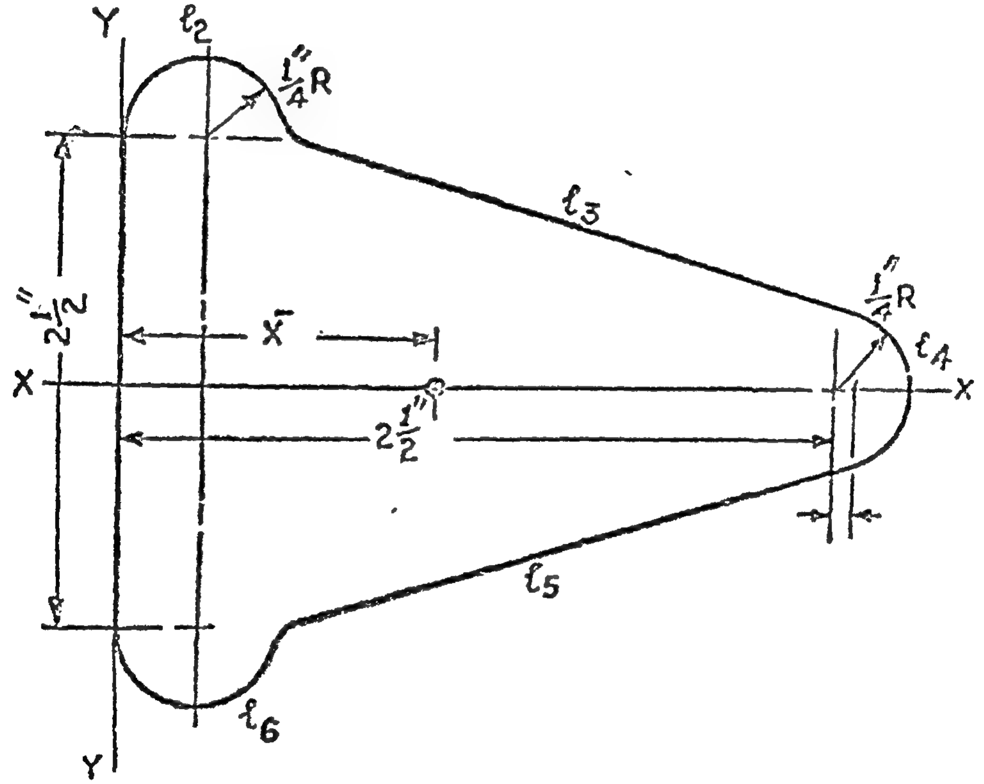


Fig. 15.09

2. Divide axes *XX* and *YY* at right angles in a convenient position. If the figure is symmetrical about a line, let this be one of axes. The centre of pressure will in this case be somewhere on the *XX* axis.

3. Divide the cutting edge into line elements, straight lines area etc. Numbering 1, 2, 3 etc.

4. Find the lengths l_1, l_2, l_3 etc of these elements

5. Find the *C.G.* of lines of length l_2, l_4, l_6, etc. In the case of semi circular ara *C.G.* of the arc are must be found out and not

C,G. of the area of the semicircle. C.G. of a semi circular arc of radius r is given by $2r/\pi$ and lies on line joining the centre of the circle to centre of the arc length at a distance of $2r/\pi$ from centre of the circle.

6, Find $x_1 . x_2$ etc and y_1, y_2 etc i.e., distance of C.G. of each line element from the axes YY and XX respectively.

7. Calculate the distance X of the centre of pressure from the YY axis by the formula.

$$X = \frac{l_1x_1+l_1x_2+l_3x_3+l_4x_4\ldots\ldots}{l_1+l_4+l_3\ldots\ldots\ldots\ldots\ldots}$$

8. Similarly find $Y = \dfrac{l_1y_1+l_2y_3+l_3y_2+l_4y_4\ldots\ldots\ldots}{l_1+l_2+l_3\ldots\ldots\ldots}$

Exact position of centre of pressure is thus determined.

In the problem the component is symmterical about XX and YY axis is also chosen on the one edge. The line elements are marked l_1, l_2, l_3, l_4, l_5, l_6 as shown. The centre of pressure in on axis XX due to symmetry and no calculation are required for Y.

Element	l	x	y	lx	ly
1.	1.500	0	.0	.000	0
2.	0.785	0.25	+.91	.196	+0.227
3.	2.350	1.50	+·875	3.525	+1.312
4.	0.785	2.66	0	3.100	0
5.	2.350	1.50	—.875	3.525	—1.312
6.	0.785	0.25	—.91	.196	+0.227
	8.555			9.542	0

$$X = \frac{9.542}{8.555} = 1.18''$$

$Y = 0.$

DESIGN OF DIE ELEMENTS

Both single operation dies like blanking, piercing, trimming notching etc., and multiple operation dies like compound, combination and progressive consist of certain components or elements which are common. Multiple operation dies differ only in lay out and complexity of the punches and dies. Design procedure for various elements of the die assembly does not differ, only the problem be-

comes complex in laying out several punches and dies in suitable places in multi-operation dies. The important elements of either classification are die block, die holder, punch, punch holder, strippers, stock stops and knock outs. It, therefore, becomes necessary to take up the design of each element separately. Having become familiar with the variety of design of various elements, the tool equipment designer selects certain designs, makes sketches incorporating the elements by laying them out suitably and prepares final dimensioned drawings (both assembly and detailed) for the ease of tool manufactures in the tool room.

Die Block Design :

The die block constitutes the female half of the two mated tools which carry the cutting edges. A vertical opening extending through the block determines the size and outline of the blank. The exact opening to be provided in the die to obtain a predetermined clearance between the punch and the die, amount of angular clearance and vertical land in the die opening to control the size of blank or hole have already been discussed. As the die block is made of superior tool steels its over all dimensions should be decided such that they are minimum consistent with strength requirements. The overall dimensions should be obtained by having minimum die wall thickness required for strength and by the space needed for mounting screws and dowels and for mounting the stripper plate.

Two and only two dowels should be provided in each block or element that requires accurate and permenent positioning. They should be located as far apart as possible for maximum locating effect, usually near diagonally opposite corners. Two or more screws should be used depending on the size of the die block. Minimum distance of a screw or dowel from the outer edge or inner edge should be $1\frac{1}{2}$ times its diameter. Die block thickness is also governed by strength requirements of the material to be punched. Infact it is the minimum area (*i.e*,, wall thickness X block thickness) which really resists the forces involved in bursting the die The minimum area provided should be effective in resisting these bursting forces. There are two methods followed in reaching at the dimensions of the die block. First one is based on experience and second one tries to base the dimensions on some calculations.

Method : 1.

For a die block made of tool steel, the thickness should be 10mm minimum for a blanking perimeter of 75 mm.

25 mm for a blanking perimeter of between 75-250mm and 30 mm for large perimeters.

There should be minimum of 30 mm margin around the opening in the die block. For securing the die block to the die holder or shoe use the following rules :

1. On die blocks upto 150 mm square use two 10 mm Allen screws and two 10 mm dowel pins.

2. On sections upto 250 mm square use three Allen screws and two dowel pins.

3. For heavier stock and still bigger blocks, use screws and pins of 12 mm dia. Counter bore the die biock to accommodate Allen heads ar least 3 mm deeper than length of heads to compensate for die sharpering.

Method 2 :

The method as given by ASTME in Fundmentals of Tool Design is based on series of tests by *F.* Strasser. Calculation of die thickness in this method is divided into 4 steps and based on tables given in that book.

Punch Design

The exact dimensions of punch on diameter are determined by providing clearance between the punch and die. If it is a blanking punch its size is less than nominal and if it is a piercing punch it is of the exact nominal size. The punch is usually designed with a wide shoulder to facilitate mounting and to help prevent deflection under load. In case of smaller punches the punch may be held in a retainer which in turn is mounted against, the punch holder. The strength of a small punch can be improved by increasing its cross-sectional dimensions above the cutting end without interfering with the strippers. Again a back up plate made of hardened steel also is necessary for a small punch to prevent hardened punch being pushed into the softer punch holder. Back up plate also helps in building the punch length. The exact length of a punch can be found out by laying the whole assembly drawing only, as

the shut height is to be made up from die block, die shoe, punch and punch holder and back up plates thickness.

Punches of diameter less than the stock thickness must be designed carefully because unit compressive stress in punches rises to 4 times the unit shear stress of the material when punch diameter is equal to stock thickness.

If d is the punch diameter in mm and t the thickness of the stock in mm and f_s the shear-strength of stock meterial, then cutting force$=\pi . d.t \times f_s$.

Compressive force that the punch can bear$=\dfrac{\pi . d^2 . f_c}{4}$

$$\text{Equating the two } \pi\, d.t.f_s = \frac{\pi . d^2 . f_c}{4}$$

$$\frac{4\, f_c . t}{d} = f_s$$

Hence if $t/d=1$, f_c is 4 times f_s.

This compressive stress is high for punch tool materials. Hence the value of d/t should not fall below 1·0. However if the hole less than stock thickness must be punched the following precautions should be taken :

1. Punch steels of high compressive strength should be used.
2. Clearance should be more than already recommended.
3. Punch should be aligned carefully. It should be finally finished.
4. Shear be proviped on punch or die or both.
5. Stock should not be allowed to slip.
6. Strippers should be designed sliding fit round the punch, punches may break while stripping.

Though the punch length is to be made up, the maximum allowable, however, can be calculated from the formula for long columns.

$$L=\frac{\pi\, d}{8}\left(\frac{E\, d}{S_c . t}\right)^{\frac{1}{2}}$$

Where $d/t=1.1$ or higher

E=Modulus of elasticity for punch material.

Only in rare cases the punches are over 4 in. in length. An allowance of 12-25 mm for sharpening should be made whenever possible in the length of punches.

Die Shoe Design :

Die shoe is made up of *C.I.* and functions primarily as a base for the complete die assembly and in turn is botled or clamped to the bolster plate over the press bed. The die shoe should be at best $\frac{1}{4}$ in. large all round than the die block. However if bolster opening is large, an oversize die holder may be needed to bridge the opening. To facilitate clamping, flange is provided around the outside of die shoe. Back portion of the die shoe should have sufficient space for guide posts and bushing also. Die shoes vary thickness from 25-75 mm.

Punch Holder Design :

The punch holder is used to mount the punch either directly or through a back up plate and retainer. It has space for push fitting of guide pins also. These guide pins slide into the lower portions of the die assembly *i.e.*, die shoe. Upper part of the punch holder is provided with a shank equal in diameter to the ram hole. The shank is locked in position with a side screw. The dimensions of the punch holder should be about 5 mm larger than the punch. If it is to be mounted it should have flanges. The Punch holder varies in thickness from 25-75 mm. Small punch holders are mounted to ram through shank only, they have no separate flanges around its edge.

Commercial Die Sets :

These days, the die shoe and the punch holder together with two or more guide posts constitute a standard commercially available die set. Two types of die sets round series digonal type and back post type are covered by American Standard ASA B.S. 15-1950 "Punch and Die sets". In addition to providing enlarged mounting bases for the punch and die elements, these die sets are equipped with heavy guide posts which maintain alignment of the two members. In practice, the tool designer studies the job to be done and then selects a suitable die set upon which he can mount his punches and dies. The die holder should be atleast $\frac{1}{4}$" larger all round than the die element. The guide post are press fitted in one

portion of the die set and move through bushes through the other. The bushings are made of hardened steel. When ordering sets, the punch holder shank diameter required to fit the press must be given. Size ranges from 40-50 mm. Also the length of the guide post and bushings should be specified. The determined shut height establishes the length of the guide posts which must be atleast 12 mmshorter to allow for reduced that height due to resharpening. The guide pins are of mild steel where as punch holder and die holder can be *C.I.* or semi steel. Back post type commercial sets of ASA B.S. 25-1950 design can be refered to in other books.

Methods of Mounting Punches :

There are a number of methods to mount punches to meet various production requirements. Blanking punches do not create much difficulty as regarding mounting and laying out. Being comparatively bigger they are provided with flanges also so the flanges are mounted with the help of dowel pins and Allen screw into the punch holder directly without the use of back up plate or punch plate fig. 15.10 (*f*) However piercing punches where d/t is about 1·1 or even less, present some difficulty because sometimes the holes are to be pierced very near to each other and piercing punches have to be designed headless to accommodate them so near each other. Methods given below illustrate a few designs of mounting punches.

1. Headless Punches.

Head-less punches can be held in the hole of the ram or punch plate with the help of a set screw which bears on flat portion machined on the body. Some punches are designed for small production runs. Frequent changing of the punch is affected very easily by loosening the set screw. Small headless punches should be provided with hardened back up plate of steel to avoid punch heads from pressing into the soft punch holder and thus working loose. Fig. 15.10 (*a*) show this method of mounting the punch. However if the punch is provided with a collar that rests against the punch plate the back up plate can be avoided as shown in fig. 15.10 (*b*) But the need for the coller makes the punch expensive to produce. A third design for a punch requiring frequent changes is shown in fig. 15.10(g). The punch is firmly locked in the punch plate or retainer

by means of the spring loaded ball pressing into a recess in the shank of the punch. To remove, the ball is pressed up against the spring by means of a piece of drill rod inserted through the hole and the punch pulled out by hand. To replace a punch, it is inserted into the retainer and pushed into place. The ball automatically presses into its seat and locks the punch securely.

2. Peen Headed Punches :

Punches less than 20 mm diameter are often made from 20 mm or smaller drill rod and are left shoulderless until assembly, when the punch is pressed tightly into a counter-sunk reamed hole in the punch plate and then riveted over. The shank of the portion of the punch placed in the punch plate is always made circular and larger

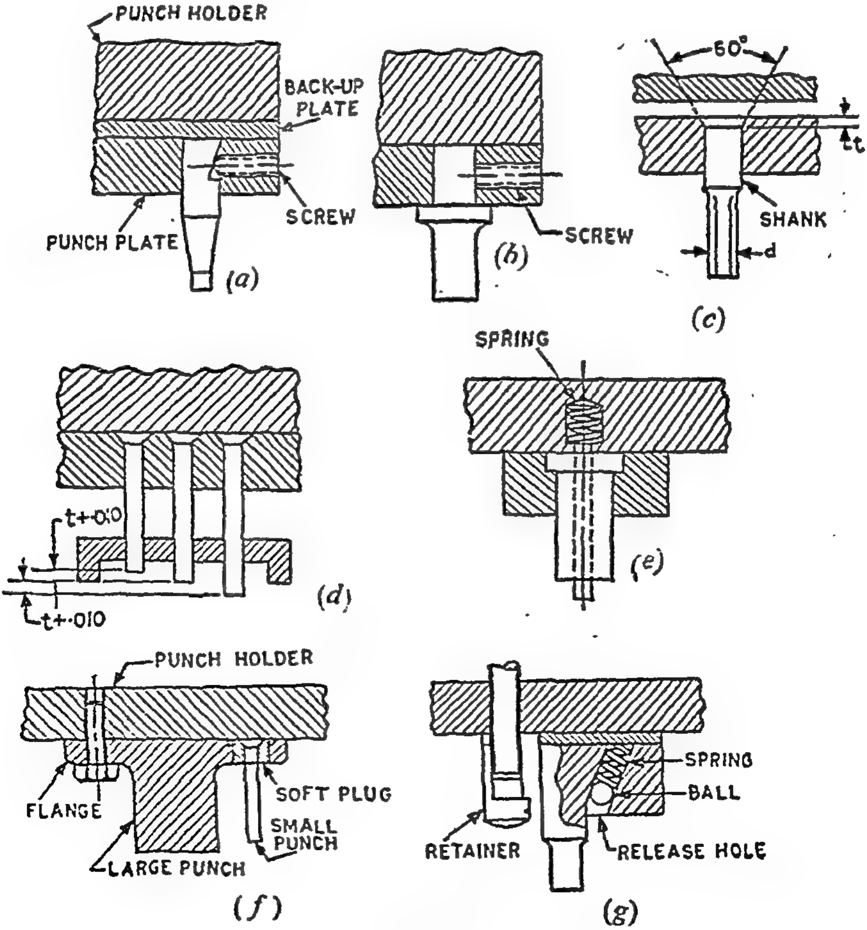


Fig. 15.10

than the piercing section in order to facilitate assembly. Dimension should be 2mm for punch dimensions up to 5 mm and 3mm for punch dimensions upto 10mm and 4mm for dimensions upto 15m this being the limit for this type of mounting. Dimension *d* is the diameter of round punches or the largest cross sectional dimension of non-circular punches. (Fig. 15.10*c*)

This type of construction on the punch head is widely used on perforating operations where a great many small round and closely spaced holes must be pierced. Slender punches for perforating are further supported and guided by making than sliding fit in the stripper plate as shown in fig. 15.10*d*. For best results the stripper plate should be hardened at the guide holes or fitted with bushings.

3. **Quilled Punches :**

For a piercing very small holes in heavy stock it is common to use a punch having a uniform point and shank diameter enclosing it in a quill which is of hardened tool steel with an internal diameter concentric to its outsids diameter. The punch is dimensioned so as to enter the die only far enough to completely fracture the stock with the quill dimensioned so as to give full bearing support for the full thickness of the stripper. This reduces shock and vibrations and extends punch life. Head of quilled punches are usually riveted over and the quill provided with a square shouldered head which is retained in the retainer.

4. Larger punches are provided with heads or shoulders. The head fits securely into the recess in the punch plate and not only is there little likelihood of any looseness developing, but the punch can be accurately located by dowelling the punch plate into position. Pressed portions should be made to a standard reamer size. Provision must be made to prevent the rotation of noncircular punches.

Large piercing punches need push off pins as shown in fig. 15.10(*e*). These prevent slugs from adhering to the punch when it rises and causes trouble.

Large blanking punches are made with flanges that are doweled into position and fastened directly to the punch holder by screws. If the flange is hardened, and a slender piercing punch is also needed, it should not be pressed directly into the flange as if it were a punch

plate but a soft metal plug should be inserted. Further the slender piercing punch should be made shorter than the larger punch by an amount equal to $t+0.2$mm fig. 15.10(f).

5. Thin rectangular punches can be mounted with the help of low melting alloys also, An alloy of bismuth, lead, tin and antimony with a pouring temp. of 350°F and the property of expanding after solidifying is marketed under the name of Cerromatrix.

Stripper Design

The primary purpose of a stripper is to remove the stock from the punch after a blanking or piercing operation. However the stripper serves two other secondary functions also. Firstly it guides the strip if fixed to the die block surfaces. Secondly it holds the blank under pressure before the punch descends fully if the stripper is of spring loaded type. Strippers are of two basic types :

1. Fixed strippers.
2. Spring operated strippers.

A simple fixed stripper fig. 15.11 may not guide the sheet, strip or work piece but with a little change in design the fixed stripper can be used to guide the work piece. Then it is called channel stripper also. Both the simple fixed stripper and

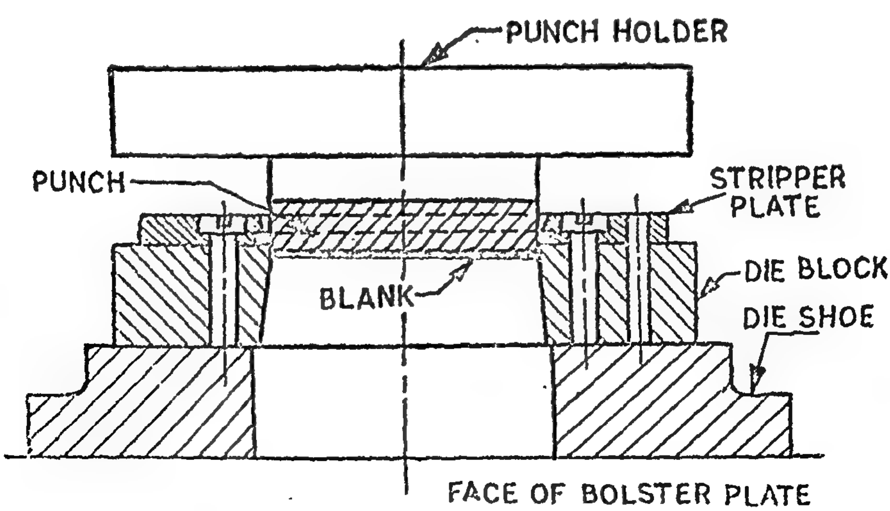


Fig. 15·11

channel fixed stripper are usually of the same width and length at the die block. The stripper is fastened with the same screws and dowels that fasten the die block and screw heads are counterbored into the stripper. However if the die block is fastened to the die shoe from below then stripper screws and dowels are independent. The stripper thickness should be sufficient to withstand the force required to strip the stock from the punch. Additional thickness is provided at sides to provide the stock channel. The addition thickness is obtained by introducing small stripper blocks or by machining the original stripper plate so as to provide a channel when fixed on the die. Screws of 10-15 mm size are used for fixing stripper to die block but in either design the thickness of stripper should be able to provide counter bores for screws heads. A 6mm thick stripper is quite adequate for normal use. Height of the stock strip channel formed either by separate blocks or by maching grooves in a thick plate is 1½ times the stock thickness. This should be increased if the stock is to be lifted over a fixed pin stop. The width the channel should be atleast 0·12 mm greater than stock width. If a channel stripper is to serve as guide properly then apart from provided variation of 0·12 mm in channel width, its length should also be at least twice the width of the stock or channel. This length of the channel is designed by extending the stripper length on the feed end. It guides the stock better then. The block length below the stripper is also extended on the feed end side by fastening a sheet metal plate to the die block.

Spring operated strippers or pressure pad strippers. Fig. 15·12 are used in ordinary blanking dies and also in compound and inverted dies. In a simple blanking die the pressure pad contacts the strip ahead of the punch and holds the material flat just before the blank is cut. There are two advantages of spring operated strippers over the fixed strippers.

1. Spring pad pressure prior to piercing operation removes all the waved irregularities in thin sheets.
2. The work performed is in full view of the operator and not covered by the stripper plate except at the time of blanking.

The principle of spring operation stripping is used not only for ordinary stripping of the punch and work but blank or rejects can also be ejected from the die openings by placing the spring and stripper inside the die whether they are in upright position or inverted position. If the spring operated stripper is used to remove blanks or slugs from inverted die it is called **Inside stripper or shedder.** If the die is in the up-right position it is called an **ejector.**

The force for which springs of the spring operated strippers are designed is taken as $F=1500\ LT$ kg.

Where F is in kg, L is cut perimeter in cm and T is stock thickness in cm.

The stripper force may be as high as 20 per cent of the blanking force. The highest of the two values is used for determining the number and type of springs required. The required travel plus preload deflection will be total deflection and will determine the length of spring required to stay within allowable percentage of deflection limits. As the punch is resharpened, deflections will increase, and should also be allowed for.

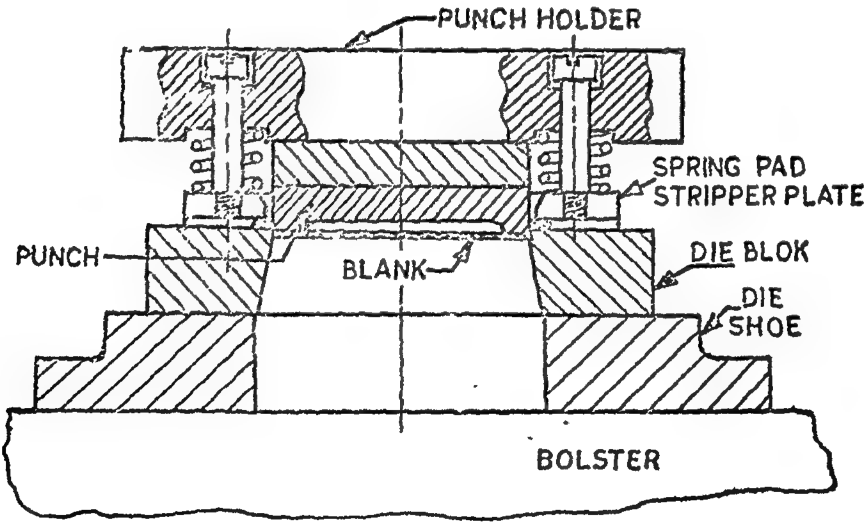


Fig. 15·12. Use of spring loaded stripper

To retain the stripper against the necessary preload of the springs and to guide the stripper in its travel a special type of

shoulder screw known as stripper bolt is used. Stripper bolts are made commercially. The round head of the bolt contains a hexagonal recess to suit Allen keys. The stripper plate in case of stripper bolts rests against a definite shoulder. The shoulder positions the stripper plate exactly when the die set is new, but when the punches are ground and thus shortened the stripper plate is no longer flush with cutting edge of the punch and washers must be placed under the head of the bolt. Arrangements of spring usefulness for stripping. is shown in fig. 15·12.

Knock outs :

Cut blank or pierced slug is made to knock out of the inverted top die by a mechanism called knock out also if an inside stripper plate operated by spring makes the design congested. Moreover the action of the inside stripper plate is not always positive if the

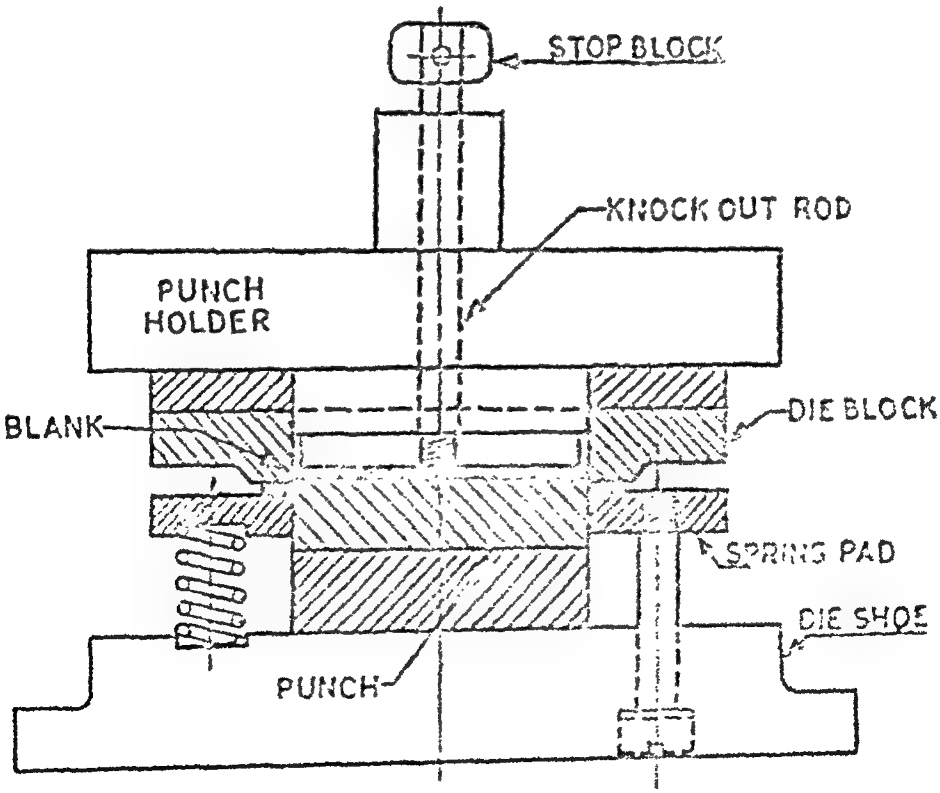


Fig. 15·13. Use of knockout and spring stripper

friction between the cut blanks and die opening becomes excessive. A knockout assembly consists of a plate, a push rod and a retaining collar. The plate is a loose fit with the die opening contour and

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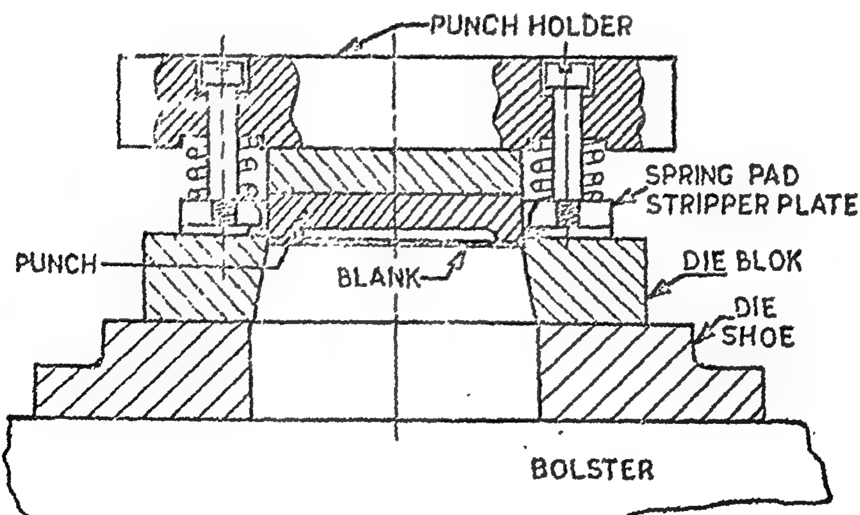

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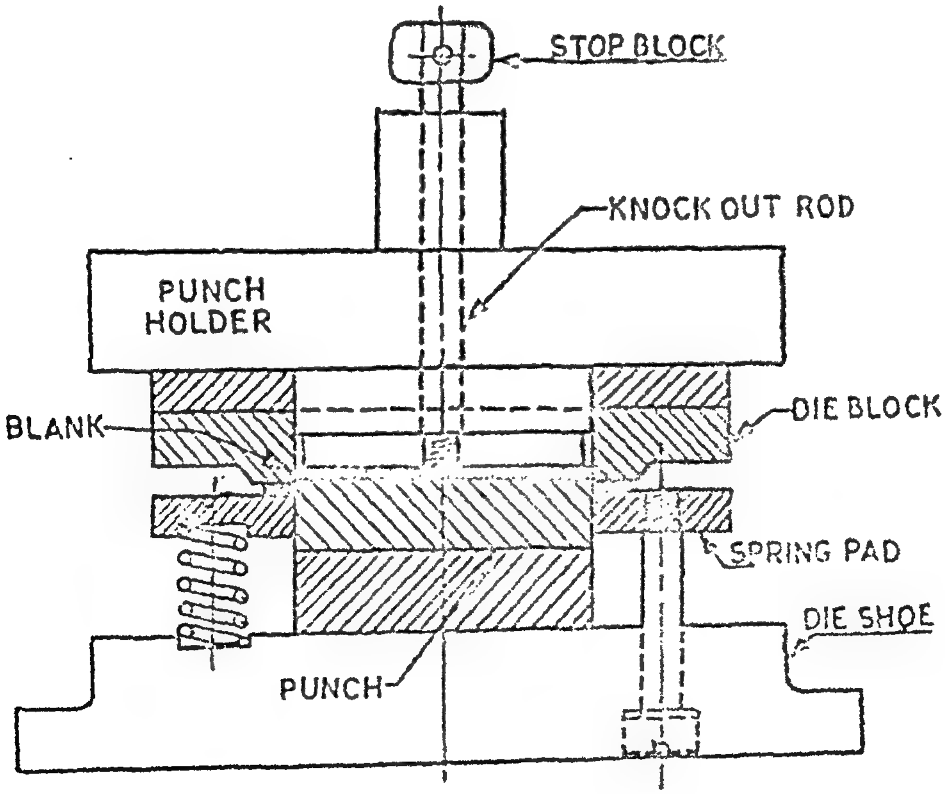

Fig. 15·13. Use of knockout and spring stripper

friction between the cut blanks and die opening becomes excessive. A knockout assembly consists of a plate, a push rod and a retaining collar. The plate is a loose fit with the die opening contour and

moves upward as the blank is cut. Attached to the plate usually by rivets is a heavy push rod which slides in a hole in the shank of the die set. This rod projects above the shank and a collar retains and limits the stroke of the assembly. Near the upper limit of the ram stroke, a knock out bar in the press contacts the push rod and ejects the blank. Fig. 15·23.

Knock outs have several advantages over an inside stripper in an inverted die.

1. Knock outs are generally of lower cost than spring strippers.
2. Action of a knock out is always positive.
3. Lower pressure requirements, there being no additional force required to compress heavy springs.

Pilots :

When establishing the sequence of operations for progressive dies, piercing oparations are placed first. Advantage is taken of these holes for piloting the blanking punches so that the blank formed is exactly concentric to the pierced hole. This piloting is obtained with the help of pilots secured under the blanking punches.

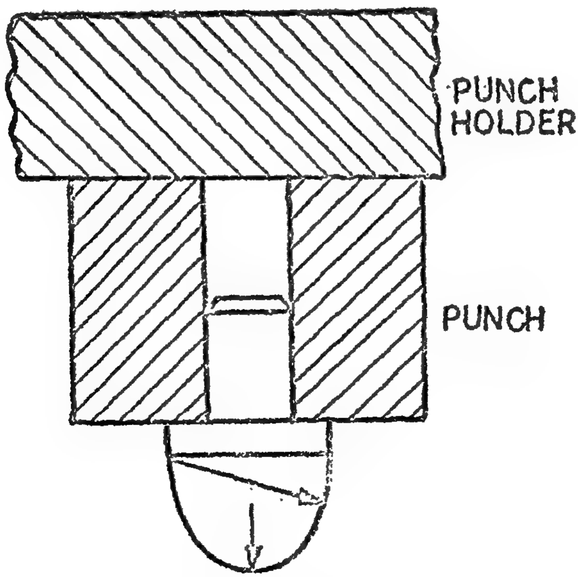

Fig. 15.14

Pilots are made of good tool steel, heat treated for maximum toughness and to hardness of Rock well C 57 to 60. There are four ways of retaining a pilot in the punch. Punch is suitably designed to retain the pilot.

1. Press fit pilots. Fig. 15.14.
2. Threaded shank pilots.
3. Screw retained pilots.
4. Socket set screw pilots.

Press fit pilots are liable to drop out due to friction between the pilot and the pierced hole and are therefore not recommended for high speed work.

Indirect Pilots :

It is not always necessary to fix a pilot to the bottom of the blanking punch. The pilots may be independent of the blanking punch and directly retained in the punch holder. Such slender pilots are well guided through hardened bushes in the stripper plates. They orientate the work for progressive operation by engaging in the holes made in scrap portion of the work. Methods of retaining such pilots are similar to those of retaining piercing punches already discussed.

Stock Stops :

The following devices can be used to stop the work in preparation to the next stroke of the ram.

1. Stop Pin :

Being simple it is extensively used in dies. It has the disadvantage of demanding considerable skill on the part of the operator. Stop pin is press fitted at a suitable place in the die block. It can be made spring loaded also so that with a little force on the part of the operator the stop pin will settle down temporarily and again rise in the next blanked opening. Stop pin can be designed to touch either diameter end of the blanked opening. One side of the pin should be tapered to facilitate pushing and downward movement of the pin, where as other side is made vertical to locate the edge of the blanked hole. The height of the stop is about $1\frac{1}{2}$ times the stock thickness or more.

2. Automatic Finger Stop :

Automatic stops differ from fixed stops of the type mentioned above in that they stop the strip automatically, the operator having only to keep the strip pushed against the stop in its travel through the die. Though automatic finger stop is more expensive than stop pin but it provides more reliable action. If the work is to be fed by the worker his job is simplified. He need not push the work piece at a particular moment *i.e.* while the work is falling after being stripped. Finger stop can be used in conjunction with automatic feeds also.

In operation, the spring exerts a constant force tending to hold the finger down and to the right. The stop is pivoted on a pin that is slightly smaller than the hole in the stop, so a small amount of side ways finger movement is possible. When the punch is descending a special adjustable trip screw fixed to to punch holder strikes pad and lifts finger.

As this happens the finger moves to the right, due to the spring action and becomes clear of the hole in the scrap stock that has been holding it. As the punch ascends, surface A is permitted to rise and the finger to descend but now the finger stops on top of the stock because it has moved to the right. When the stock is pushed to the left the finger drops into the next blanked hole, registers with the right hand side and is pushed back to its former position ready for another stroke.

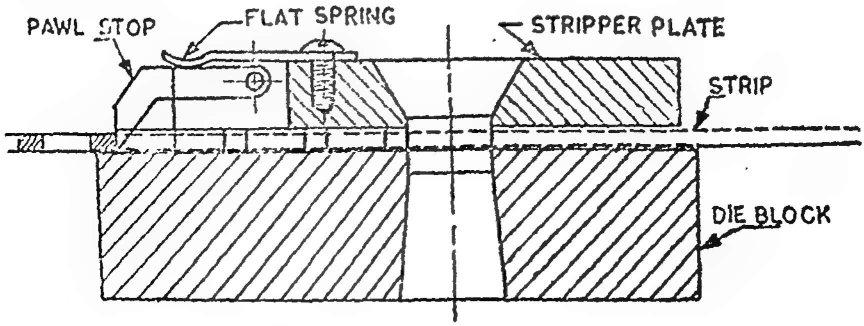

Fig. 8.15 A Pawl type stop

Pawl Type Automatic Stop :

It is a cheap and efficient stop that can be easily installed and seldom needs attention or repair. It is operated by the movement of the strip and is entirely independent of the punch movement. As implied by its name it is simply a horizontal pawl or lever secured on a fulcrum pin fixed in the stripper plate. The pawl lifts up against a flat spring, when the strip is fed under it and its point drops into

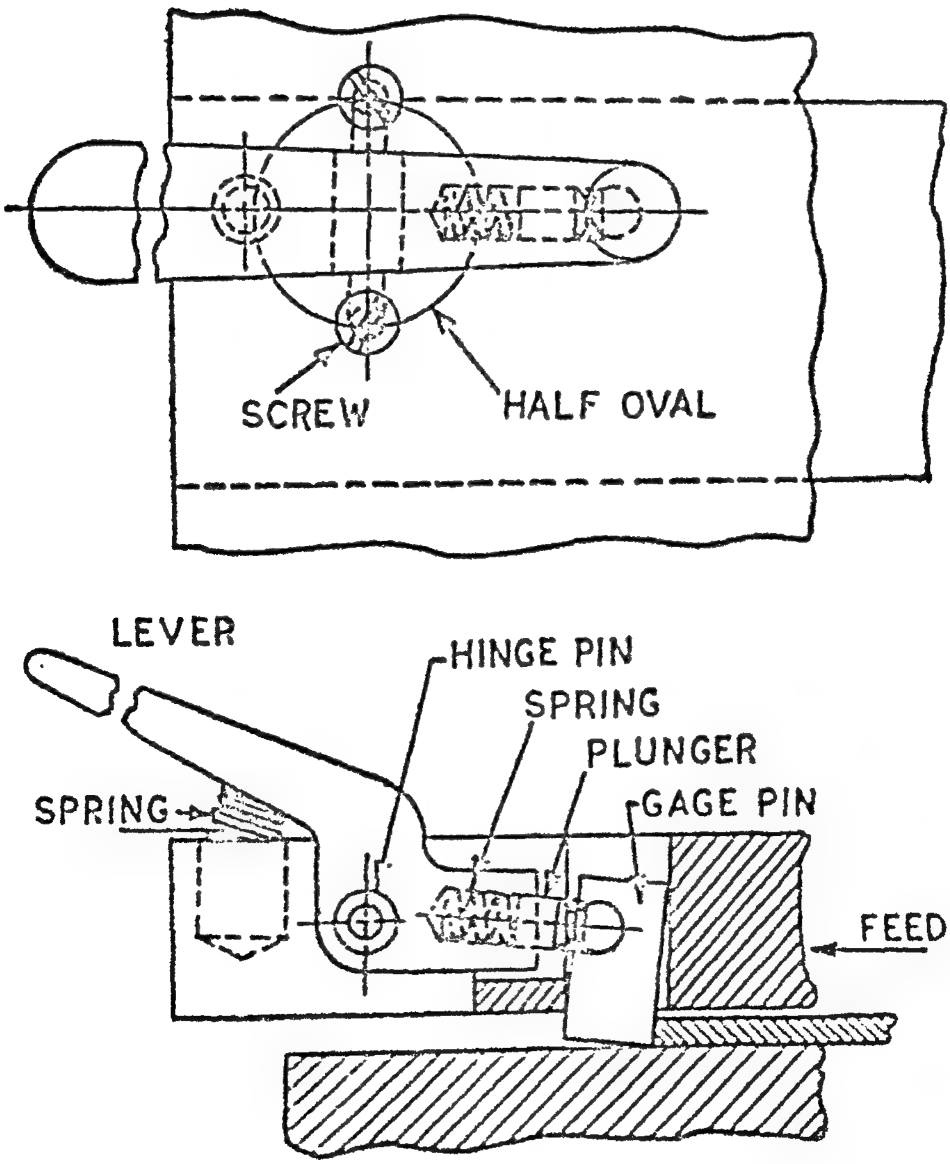

Fig. 15.16

the next blanked opening. The operator then pulls the strip back slightly, until the left edge in the blanked opening registers against the point on the pawl. Fig. 15.15.

Standardised Automatic Stop :

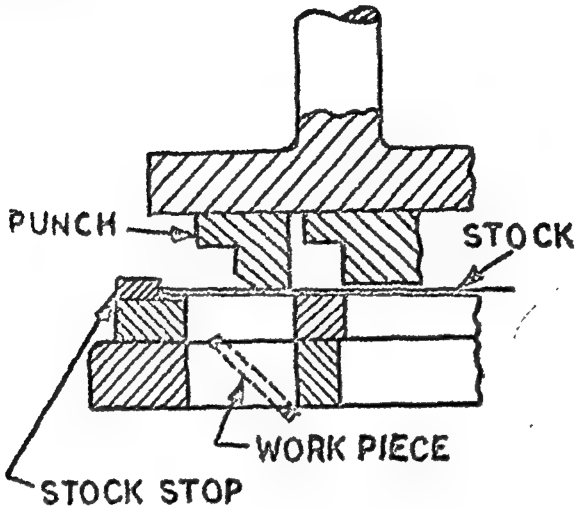

Fig. 15·17 a

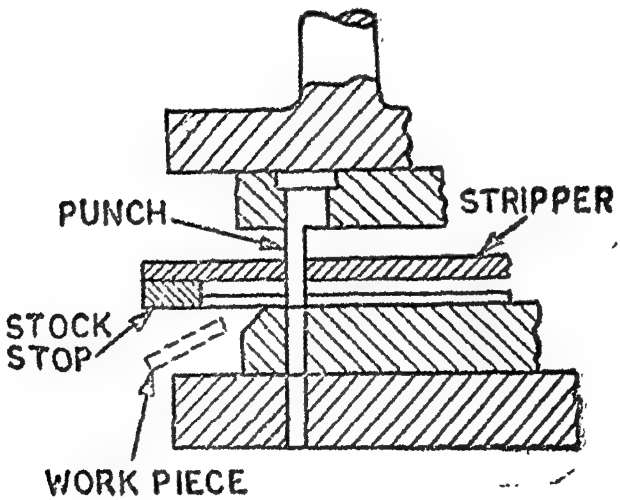

Fig. 15.17b Shoulder Stop

These are many commercial stock stops available for purchase from die set manufacturers. These have been standardised by the firms. Danly Auto Gauge is one of such automatic stops (fig. 15.16.)

widely used for high speed operation. The design consists of a gauge pin which fits loosely in a hole in the stripper with the help of a plunger and a spring, normally held in a lever. The strip advance lifts the gauge pin to the slanted position. Ram descends and causes a trip fixed to punch holder to push the lever down and the gauge pin is lifted above the strip. Plunger spring now pushes the gauge pin on top of the scrap bridge. Upon forward movement of the trip, the gauge pin falls inside the hole just blanked.

Shoulder Stop :

This type is extensively used on progressive dies where last operation is a cut off or a trimming one and no skeleton of scrap material is to be passed out to the other side. The shoulder stop is as wide as the stock. It can be fastened either to the die or to the stripper plate. In both cases, there should be clear space at the end of the set for the disposal of the work piece. Fig. 15.17 (*a* and *b*)

Scrap Strip Layout :

For an economical utilisation of stock, it is necessary to make a layout to show how the blanks can be best be produced from the stock strip. This layout should show the relative positions of areas to be blanked out, so arranged as to assure maximum utilization of stock material. The aim should be atleast 75 per cent utilisation. The lay-out can be facilitated by making several templates from stiff paper, card board or even the actual work material cut to scale in the shape and sizes of the desired blank. These can be shirted around in various arrangement between parallel guide lines representing edges of the stock strip. When the best possible arrangement has been found, the layout can be drawn up and dimensioned.

Unless a stock edge becomes a blank edge the layout must allow sufficient stock between areas to be blanked out and between edge of cut and side edge of stock to leave a web or sc[illegible] tsong enough to resist breakage while in press working

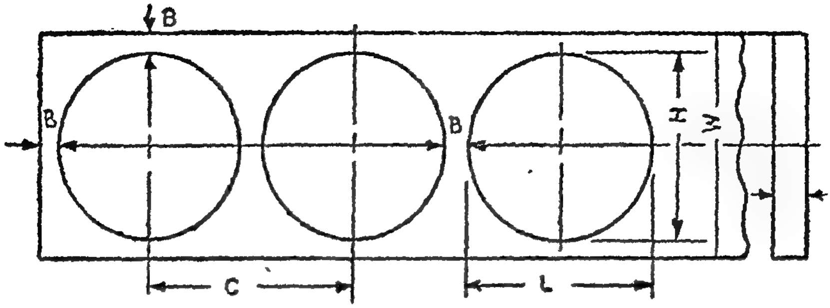

Fig. 15 18

15.18 shows a simple scrap strip layout for a circular blank. B is the space betwhen part and edge of strip or it is space between two blanks. This space between two blanked spaces is called bridge allowance also. C is the lead of die that is the distance by which the work stock should be advanced for next stroke of the ram. It is the distance from a point on one part to the corresponding point on the next part. L is the length of the part, H is part width, W is the width of the scrap strip and t is the thickness of the stock. For an efficient cutting and economical utilisation, value B should not be unnecessarily large nor too small. The following formula are used in calculating scrap strip dimensions for all strips over 2 mm thickness.

If : t=specified thickness of the material.

$B=1\frac{1}{4}\,t$ when C is less than 60 mm

$B=1\frac{1}{2}\,t$ when C is 60 mm or larger

$C=L+B$

If the material to be blanked is less than 2 mm thickness the dimensions of B are as follows :

Strip width W mm	Dimension B mm.
0—75	1.25
75—150	2.25
150—300	2.25
over 300	2·75

The bridge allowance varies from $1\,t$ to $1\frac{1}{2}\,t$ depending upon the outline of the blank.

The stock strip layout, thus determined, gives the idea of the width of the strip. The strip of this width is sheared in preparatory machines out of standard size sheets available from producers. The strips so obtained are sent to press work sites as stock strip materials. Stock strips of standard width are also available. Tool designers effort should be to choose a strip of standard width and effect maximum utilisation. For such purpose double row blank layout (Fig.

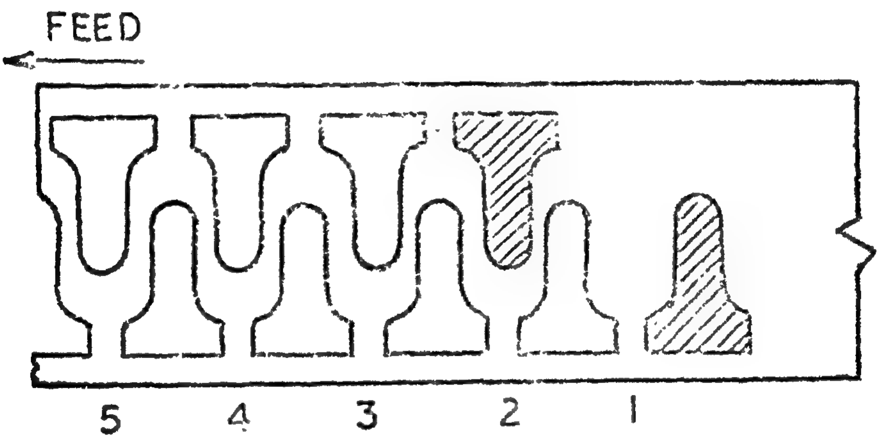

Fig. 15.19. Double row blank layout

15.19) should also be checked. Double row blanks may be of single pass or double pass design. Single pass design utilises two punches where as double pass design utilises single punch.

In a double pass design the strip is to be overturned for the second pass.

Design Procedure for a Blanking die :

1. **First step** : In designing of press tools, first step is the making of sketch incorporating all elements of die. This sketch is then given dimensions in a systematic manner in which parts are assembled. There are a few designs of blanking dies. Which design is selected for making the sketch is also decided by the tool designer considering the size and shape of the blank and also the restrictions placed by the press available. Blanking dies are mainly of two types :

1. Drop Through dies Fig. 15.11.
2. Inverted dies. Fig. 3.20.

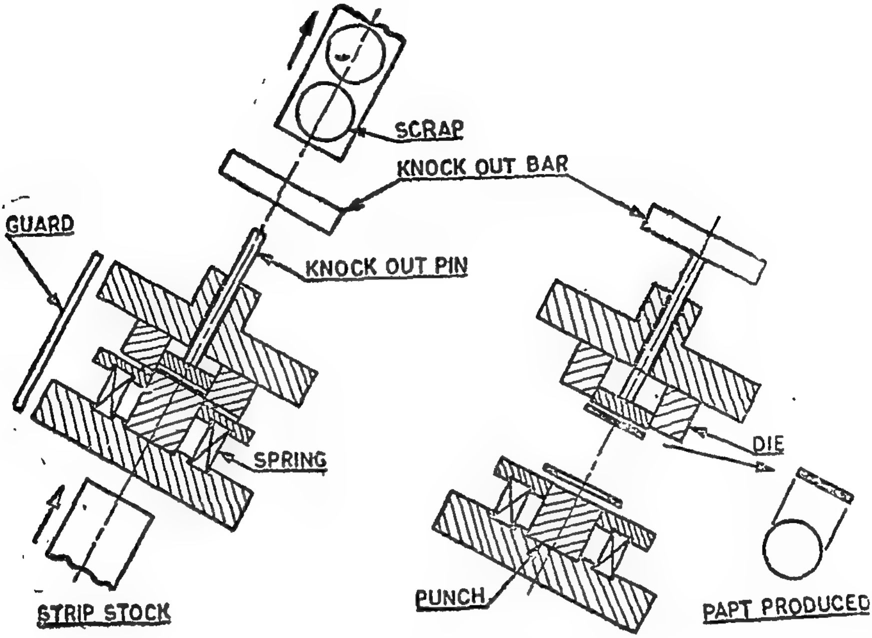

Fig. 15.20 Inverted dies

Drop through dies are higly simplified ones and are economical to build and maintain. The blank drops due to its own weight through the opening provided in the die half of the assembly. Inverted design is some what complicated however this design is used where the blank is too large or heavy to permit drop through construction or blank is too fragile to be dropped very far. In inverted die design the blank is pushed out with the help of a knock out and is pushed in the back of the press with the help of some mechanical device. Blank can be brought to the die level again in conventional dies, also by incorporating inside spring loaded stripper. Hence a particular design suitable for the conditions incorporating all necessary elements of a blanking die is sketched as the first step toward die design.

2nd Step : Determine punch and die opening diameters considering whether the operation is of blanking or piercing.

3rd Step : Design the die block as regards its over all dimension and surface area and select a dieset out of the available for the particular die block dimensions and decide the number, size, location of dowel pins and allen screws.

Figure 15.19 and Fig. 15.20 show a blanking die of two different designs for the component. Length of the punch is determined next after computing the thickness of the punch holder, backing plate, the shoe and the block. Overall length of a punch is equal to shut height minus computed thickness. Small adjustments in shut height are possible and are made if needed.

4th Step : Provide arrangement for fixing the punch in punch retainer. Choose one out of many illustrated earlier considering whether it is a blanking punch or a piercing punch Special precautions are always needed to fix and guide slender piercing punches.

5th Step : Provide stock stop, stock guide and suitably designed stripper and provide dimension to each part as also its exact location on the die block or die shoe. Design the springs of pressure pads if they are incorporated in the design.

6th Step ; Next prepare the dimensioned assembly drawing which should show the following views.

(*a*) Sectional elevation similar to the sketch above, punch in the position of just completing its downward stroke.

(*b*) Plan of the lower portion showing die block, die shoe, stripper, stop pin positions and method of securing each.

(*c*) Plan of Punch assembly looking from below again showing the position and method of securing punch, dowels and screws to the punch plate through the back up plate and retainer.

(*d*) Side sectional elevation of the punch and die assembly.

7th Step : Indicate the press capacity and type of press where the job can be handled, on the drawing.

All the above views are necessary for laying out and assembling the die elements in the tool shop where as detailed drawings are also made separately for the sake of process planning and manufacturing each component by routing through various shops. Fig. 8.20 shows an inverted die complete with all the views. Detailed drawings should be completed separately.

Steel rule dies :

Very soft and flexible materials like cork, paper, cloth and leather etc. are blanked with steel rule dies instead of blanking dies

of tool steels. The steel rule bent to the contour of the blank outline forms the cutting edge of both the punch and die. The steel rule so formed is suitably fixed to punch and die members. The strippers can be of cork, or similar resilient sheet material to force the work material out of the shallow die-cavity.

Compound Die Design Procodure :

A compound die performs two or more cutting operations of blanking or piercing at the same press stroke and at the same station. Compound dies are selected due to following reasons :

1. They are extremely accurate.
2. The finished part is less distorted than in any other type of die.
3. Compound die forms all burrs on the same side of the blank.
4. Parts produced are, identical.

Unlike a blanking or piercing die a compound die serves both as an inverted blanking die and a drop through piercing die. The blank pushed into the inverted die is knocked down on to punch by two means *i.e.* either by a knock out device or an inside spring loaded stripper (Shedder). The die has no angular clearance in the inverted design. The blanking punch serves as die block for the piercing operation. It has angular clearance for the slug to fall down. The blanking punch is surrounded by pressure pads to strip the scrap. The stripper plate monnted on the stripper bolts has stock guides on both sides. The piercing punch passes through sliding fit hole in the knock out plate or shedder plate and is retained at the top by retainer which secures both the piercing punch and die to the upper die shoe. So once the sketch Fig. 15.21 is completed incorporating all elements of the compound die, the rest of the precedure is same as in blanking dies. A compound die consists of the following components :

1. Die block.
2. Blanking punch.
3. Piercing punch.
4. Shedder or knock out device.
5. Spring stripper.
6. Die sets.
7. Stock stops.

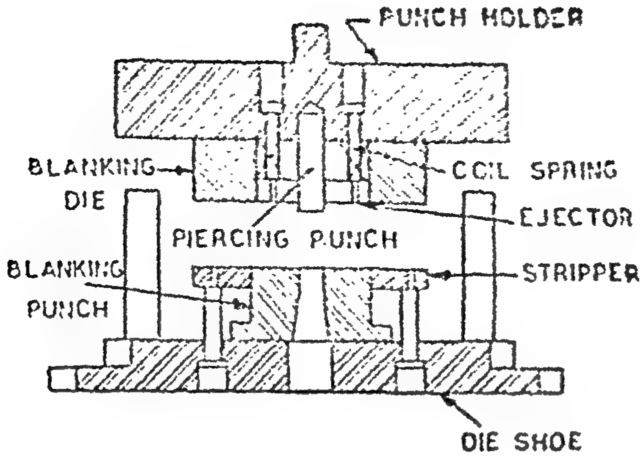

Fig. 15.21

Progressive Die Design Procedure :

The field of progressive dies has become verp wide now. Ordinary progressive die was used to perform only blanking and piercing operation at two different station with the stroke of the press ram. But these days the progressive dies are used to blank. pierce, bend, curl, draw, emboss and shear at different stations during the same ram stroke. Here aim is to discuss progressive dies for cutting operations only. As the operations increase the design of a progressive die goes on becoming complicated,

Most important first step of a progressive die design is the lay-out of the scrap strip development which shows the and their sequence. Minimum bridge allowance, is the same as already mentioned. Piercing operations are done first and they serve as pilots for subsequent blanking operations. The blanking and piercing punch should not be of the same height to avoid a large press tonnage requirement. Different stations should be so spaced that the punches can be fixed to the punch plates. If the space available is too, short than lead of the die should be doubled. Actually the sequence of operations which determine the stations is arrived at by tracing in the reverse, step by step until the original flat strip is arrived at.

2nd Step : Taking offsets from the development, make a sketch of the progressive die in sectional elevation. Find out the capacity of the press required.

Remaining steps are the same as discussed in blanking die design. Die block dimension, puch dimension, spring dimension for strippers are determined in the same manner. Die sets are chosen from amongst the standard ones or they can be suitably designed for length of die block required Fig. 15.22 shows complete assembly drawing for a simple progressive die.

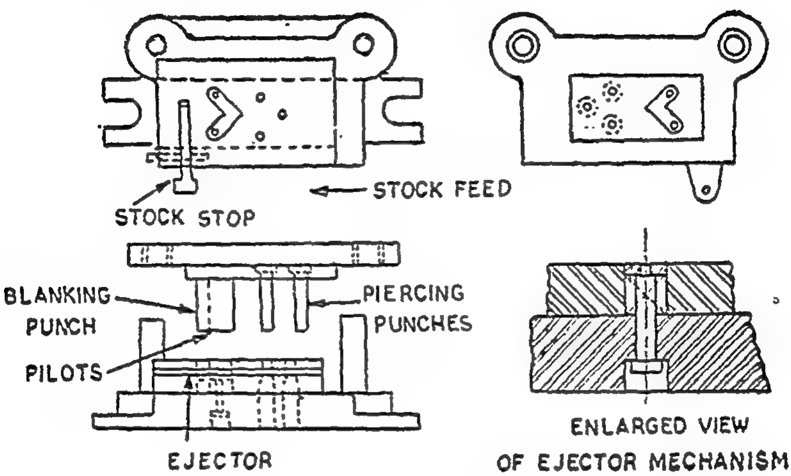

Fig. 15.22

Bending Dies :

Bending operations impart a straight bend or create an angle without any appreciable stretching of sqeezing the metal. Any internal movement of the metal is localised and does not affect the total surface area of the blank. Bending operations are performed with the help of a punch and a die which are mounted either on presses or press brakes. Press brakes are specially useful for long bends and can be utilised to perform double bends required in furniture and steel ware construction. Both the die and punch are machined to the the shape of the part. They are mounted on the press brake or press The blank is supported on the outer ends of the die but has no support directly under the section subjected to pressure from the moving punch. The punch bottom descends until separated from the stationary member only by the thickness of the work material. Such a bending is known as V bending.

Bends of 90° or less on edges of plates can be obtained by other means also. The blank is held on the die block with the help of pressure pad fixed to thedescen ding punch. The descending punch

orces the material on the die during its down ward stroke, bending t to the shape required. Such a bending is known as edge bending.

Bends of more than 90° can also be produced by using cam action dies to be discussed later.

Blank Length :

The total length of the blank before bending is obtained by adding straight lengths on both sides of the bend and the length of curved section before bending. The length of material in the curved section before bending is called bend allowance.

$$L = A + B + D$$

Where L=Length of flat blanks.

A=Length of one straight leg.

B=Length of second straight leg.

D=Bend allowance

The bend allowance varies with the distance of neutral plane from the inside surface of the bend. For a flat surface the neutral axis is in the middle of the thickness. As the material is bent more and more the neutral axis tends to shift towards the centre. The bending allowance D is given by fig. 15.23

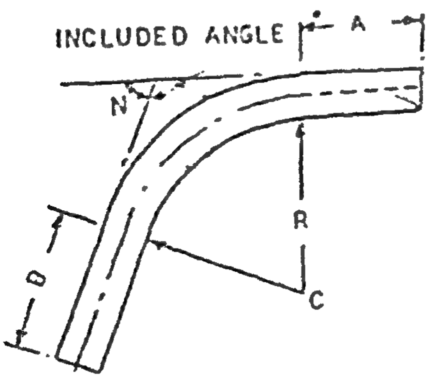

Fig. 15·23

$$D = \frac{2\pi N}{360}\,(R + Kt)$$

Where N=bend angle in degrees. This is different from included angle and is=180—included angle

R=the inside radius of the bend.

t is the thickness.

K is less than 0.33 where inside radius is less than $2\,t$ and is 0.50 when inside radius is more than $2\,t$.

Spring Back :

If the bending die is manufactured with exact bending angle the part fabricated out of such a die will not give the exact angle but somewhat less. Though bending operation is a plastic operation some sort of elastic stresses are always present which try to bring the sheet to its original shape, and the bending angle decreases. This movement of the bent sheet to decrease the bend angle is called spring back. To avoid spring back, bend angle should be increased by a certain amount fig. 15.24 when manufacturing dies, so that after

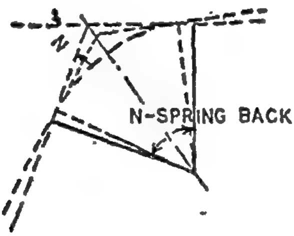

Fig. 15.24

spring back of the bent work it gives the exact angle. Spring back in steel varies from ½ to 5° depending upon its hardness; for phospher bronze it varies from 10-15°. Exact spring back is determined after experimentation only.

Bending Radii

Although an inside radius of bend equal to three times stock thickness is preferable, a radius as small as one stock thickness can

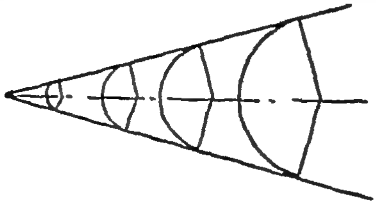

Fig. 15.25

be safely drawn on most materials. This applies to 90° bend. A sharp bend can also be obtained of the above radii on more ductile materials. The inner surface of bend is in compression and the outer surface is in tension. Too small a bend radius for the same bend angle ruptures the material when its ultimate limit has been reached. Bend radii and bend angle are two different entities. A 90° bend can be of 0° inside radius also where as upper limit of inside radius can be infinity, fig. 15.25

In general greater the thickness, hardness, or rigidity of the material, the greater the radius required to avoid fracturing. Magnesium for example requires a radius of upto 20 times stock thickness. Also greater the bend angle, greater the radius required.

Air Bend Dies :

V type bending operations are best performed on bend dies in which only bending action takes place and there is no squeezing of the metal just below the sharp edge of the punch causing reduction in thickness. In air bending dies the metal being bent is contacted only at the punch point and two edges of the die opening. Thus all the pressure is used in folding the metal and none in squeezing it. Such dies are primarily for forming heavier gauge of metal where extreme accuracy is not usually required.

Width of Die Opening :

In *V* bending dies, the width across the top of the opening in the die block has an important effect in bending results. When the width is too short an imperfect angular bend is produced. Width of of the die opening and width of the punch should be sufficient to insure a definite set in the work angle at the completion of the press stroke. Die opening width in practice should not be less than twelve times the thickness of the material. It should be fifteen times the thickness if the material is 1 mm thick or less.

Bending Pressure :

When a rectangular beam simply supported at the ends is loaded at the centre and bent beyond its yield point the bending moment has a magnitude

$$M=\frac{b.t^2}{4}Sy$$

Where Sy=stress at yield point.

b=Width of the beam.

t=thickness of the beam.

If P_t is the bending load and W is the width of V or span of beam.

$$M=P_t\frac{W}{4}$$

Equating the two

$$P_t\times\frac{W}{4}=\frac{b\,t^2.Sy}{4}$$

$$P_t=\frac{bt^2\,Sy}{W}$$

Since values of ultimate tensile stress are much more common than values of yield point it will not make much difference if S_y is substituted by S the ultimate tensile stress thus

$$P_t=\frac{b\,t^2\,S_t}{W}$$

For channels and U bends the bending pressure is twice the above value while it is same for edge bending.

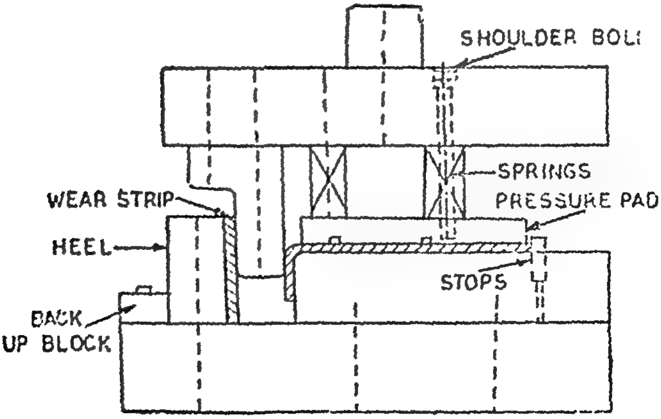

Fig. 15.26

Edge Bending Dies :

In edge bending dies the material instead of being placed over the width of the die opening is made to lie on the supporting die like a cantilever beam. The bending punch forces the metal against the supporting die. The work piece is clamped to the die block by spring loaded pad before the punch contacts the work piece to prevent movement during downward travel of the punch. The total spring pressure of the springs must be larger than the bending pressure to avoid slipping. The springs are held in place with the help of pads to which bolts are secured as in other type of dies. If apart from bending some short of ironing of the bent portion is also required the distance between punch edge and supporting die is controlled closely with the help of a heel and wear strip which prevents deflection of the punch fig. 15.26. Ironing requires more pressure than bending. The pressure pad springs should also be designed for ironing than simply bending.

Forming Dies :

Forming dies bend the metal along any contour, simple or complex, by confining the blank between two tool surfaces having identical contours one in reverse of the other which are directly reproduced in the work pieces. The shape of the blank alters without any appreciable stretching or compression of the materials. Internal movement or plastic flow of the work material is localised and has little or no effect on the total area or thickness of the blank. Forming dies are of two types :

1. Solid forming dies.
2. Block and pad forming dies.

Solid Forming Dies :

V bending dies are solid forming dies of simple nature bending the material in a straight line. When complex contours are to be bent or formed, both the punch and die are sunk to the required contour and depth with great care leaving the thickness of the metal to be formed as gap alround between the punch and die when punch is in its bottom most position. This is achieved with the help of a male and female template. The male template is made to the contour that

will be shaped on the punch. This male template coincides with the inside of the formed work piece. The female template is made to the outside contour of formed work piece. The female template is used to shape the die cavity in the die block. By doing so allowance has been made for the thickness of the metal when both die halves are set in place. Preparation of solid forming dies is an expert job because the dies must be precise and finished finely for accurate work.

When the formed work piece is difficult to remove either from the punch or die, spring ejector or spring loaded strippers are also incorporated in the punch and die. A small forming punch and die block is fixed to the dies set in the usual way and are properly guided throughout for accurate work. In big forming dies used in hydraulic press both the punch and die block are fixed directly to ram and bolster plates.

Block And Pad Forming Dies :

Pressure pad principle is used in forming dies in two ways. In one case where bottom is to be flat whole bottom of the die is replaced by spring loaded pad which is guided in the die opening. The sides of such a cavity conform to the contour required in the job. Pressure pad is upto the level of the die block and the work to be processed is laid flat on the platform consisting of die block and pressure pad. As the punch which is less in length and breadth by twice the thickness of the material descends, the pressure pad is pressed down till the maximum travel is attained. As the punch moves up the spring pressure ejects the formed part to the surface. The die contour may be formed by several blocks machined separately instead of sinking one solid block.

Pressure pads are used in another way. They hold the job on a supporting block while a hollow punch coming from above forms the ware round the supporting block which is made to inner surface of the ware and punch inner contour conforms to outer surface of the ware. Punch may be a solid punch in separate pieces if the work material is to be formed on one or two sides only. Punches for inverted forming described here are prevented from deflection by having heel blocks and wear strips. Wear strips are

replaced when worn out to keep the punch in its path. Heel block is further fixed in position with the help of a shim which is bolted in position to back up plate or die shoe or bolster directly.

Developed length is calculated for finding out the bending pressure, by the formula mentioned earlier. Total spring pressure should be more than this for calculating the springs, when the punch starts forming. In both cases the blank to be formed is placed in a nest provided round the die opening or supporting block so that it is similarly placed. The nest may be formed with the help of pins called gauge pins or gauge blocks.

Cam Action Forming Dies Or Side Forming Dies :

Certain forming and piercing operations are required to be formed from the sides also. The tool, whether it is piercing punch or a forming punch, is pushed from the side with the help of a cam provided on the side punch. The cam taper is provided on the side punch and the follower which moves horizontally is well guided and contains the side forming punch or a piercing punch. The side punch is well supported with a heel block. The central punch or holding pads are spring loaded in such designs.

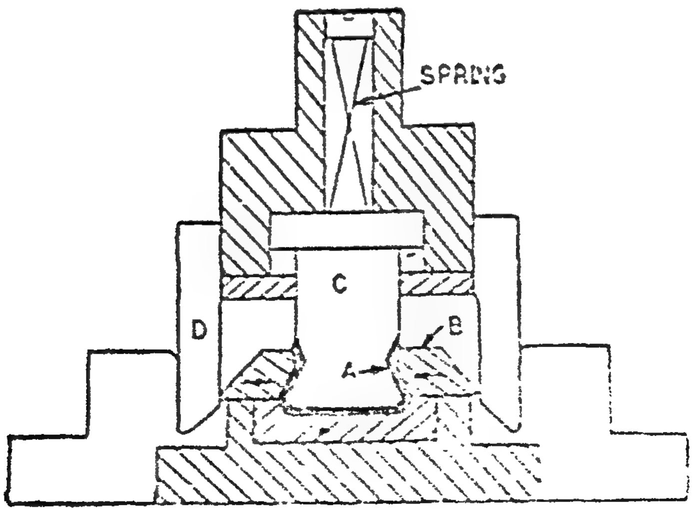

Fig. 15.27

A die with side forming cam is shown in the figure 15.27 for the finished part A. The bank is positioned between stops not shown but fastened on the tops of the side forming cams or slides *BB*. When spring punch decends on the blank and before the side punches *D* contact and start moving the slides, the work is drawn up *U* shaped between the noses of sides *BB* ; The punch then carries the *U* shaped work down on the face of the die. The ram continuing in descent compresses the spring and simultaneously forces the side punches *D-D* to advance the side forming cams inward. At the bottom of the press stroke the bottom and sides of the work are formed to size. At the top of the press stroke the formed piece is pushed from the punch with a hand tool.

Drawing Dies

Drawing operations impart a radical change to the blank. A flat circular blank can be drawn into cups, shells or cylindrcial shaped objects like cartridge primers with the help of drawing dies in which the metal is drawn over a continuous diameter edge in a die cavity. Flow of metal occurs throughout sizable areas. Side walls of the drawn pieces are continuous. This distinguishes drawing dies from forming dies where the side walls may not be continuous. More over the streching if any in case of forming dies is localised.

Theory of Drawing

The drawing operation is performed by means of a mated pair of forming members, the punch and the draw ring or die. Flat circular bank is centered over the mouth of the die which is machined to the outside contour of the desired shell. The punch is forced down against the flat blank by action of the press ram. As the punch descends at a suitable speed and the elastic limit of the work material is exceeded, the work shapes itself around the end of the moving punch and is drawn down through the draw ring or die.

The section of the blank first contacted by the flat end face of the punch becomes the bottom of the shell and relatively little plastic movement occurs in this area as it is pushed down by head of the punch. The remaining outer ring shaped metal piece, thus is available for side walls of the drawn shell. The descending punch

pulls this annular ring shaped piece down into the die opening to form the side walls of the shell. Outer primeter of the blank becomes the edge around the open end of the drawn shell. Thus a sharp diameteral reduction, of the workpiece takes place alongwith considerable displacement of the metal to form smooth and wrinkle free side walls.

The continuous ring shape of the outer metal offers considerable rigidity and will not merely fold up against sides of the moving punch as it is the case with unrestrained ends of a blank being bent. But such a condition will cause wrinkles on the sides. Due to excessive wrinking the sides may even buckle and fracture. To avoid metal folding round the punch it is necessary to hold it flat between the upper surface of the die and the face of a blank holder. The amount of pressure provided by the blank holder should be just sufficient to prevent wrinkling and yet be light enough to allow the material to slip in the drawing force direction.

As the punch descends the plastic limit of the material is over come and a plastic flow is initiated. There is elongation in the direction of draw. The metal that is shown in from the outer section to form the side walls is under compression and the thickness of the blank increases before elongation starts taking place. However after complete drawing the thickness may even be slightly less than the original stock thickness. Thus, metal displaced in one direction in compression along circumferential flow lines seeks movement in another direction as it reaches its compression limit. Flange is under compression and sides under tension. Blank holder allows the metal to flow inwardly uniformly and stretching eliminates the danger of wrinking by reducing the wall thickness.

Because of thickening at the point of compression limit each side clearance provided between punch and die must be greater than the original thickness. It may be as high as 1½ times the original thickness in some cases.

Classification of Drawing Dies :

Drawing dies may be classified in two ways. Firstly according to blank holder design secondly method of drawing. A single action

die has one ram and both the punch the and blank holder pad are actuated by the same ram stroke. Double action dies are used in double action presses, the blank holder is fastened to the outer ram which descends first and grips the blank, then the punch which is fastened to inner ram, descends forming the part. Blank holder of a double action die is different from the blank holder of a single actions die. It is a solid block fixed to the ram alround the punch where as in the single action die it consists of a pad, springs and strippers bolts.

According to the other classification the drawing dies can be classified as ;

1. Drop through or push through dies.
2. Inverted draw dies.

Both kind of dies can be designed for use on single action or double action press.

Drop Through Dies :

A simple type of drop through die is shown in fig. 15.28 It is without auy pressure pad or blank holder to hold the blank. The pre cut blank is placed in the recess on the top of the die and the punch

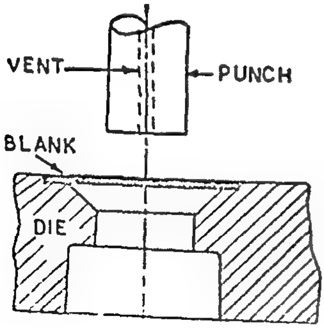

Fig. 15.28

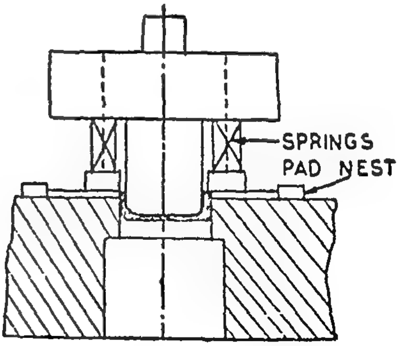

Fig. 15.29

descends pushing the cup through the die. As the punch ascends, the cup is stripped from the punch by the counter bore in the bottom of

the die. The top edge of the shell expands slightly to make this possible. The punch has an air vent to eliminate suction which would hold the cup on the punch and damage the cup when it is stripped from the punch.

Another type of die for use in a single action press is shown in figure 15.29. Here a pressure pad held by the punch holder is introduced to control metal flow. However the drawn shell is still stripped from the punch by the counter bore. This method is more effective than first one to prevent wrinking. This die can both be a single action die or a double action. If the shell is not to fall down then it can be made to eject by introducing inside stripper or ejector.

Inverted Draw Dies

If the final shape of the drawn shell is such that it is impractical to drop through the die and where the pressure on the blank holder is to be more evenly controlled by a die cushion or pad attached to the bed of the press, it is common practice to invert the forming members. The punch is mounted to the lower shoe and pressure pad is also mounted around the punch at the same level. The die is mounted on the upper shoe and moves with the press ram. Within the die cavity a positive knock out plate is usually used. This is actuated by the knockout arrangement provided by the press. Blank is positioned in the nest on the upper surface of the die cushion. The descending die draws the work material down over the draw punch. On the up stroke the pressure plate rises as far as it can, stripping the cupped work up off the punch. At or near the top of the ram stroke, the knock out plate is actuated and sheds the cup from the die cavity.

Secondary Push-through and Inverted Draw Dies :

Secondary draws or redraws which are necessary in deep drawing to final diameter require some difference in die design. In redraw dies for double action presses, a pilot punch or draw sleeve, outside diameter of which closely fits the inside diameter of the predrawn cup or shell, is actuated by the outer slide of the press. It holds the predrawn shell. The draw punch mounted on the inner slide descends through the pilot punch. Pilot punch ensures stripping

from the draw punch and some sort of ejector then ejects the shell from the die.

For single action presses a push through die simply employs a long nest to properly locate the redrawn shell and does not use a pilot or blank holder. For inverted dies in single action presses, a draw sleeve whose outside diameter is close fit in the predrawn shell is mounted round the draw punch on springs within the bed. In operation, the predrawn shell is located over the drow sleeve. The descending die draws the shell over the draw punch depressing the draw sleeve round the punch. Both knock out in the die and draw sleeve bring the drawn shell out.

Drawing Die Design Considerations :

So far sketches of various types of drawing dies have been given to make tool designer familiar and to enable him to choose a design. While giving dimensions to the die and punch the various factors that demand expert knowledge are the following :

1. Calculation of blank diameter :—Fig. 15.30

If D is the blank diameter

d is the shell diameter

r is the corner radius

h is height of the shell

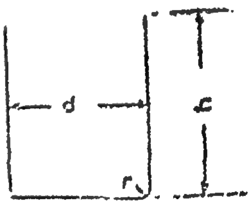

Fig. 15.30

then for thin shells where wall thickness t=bottom thickness T

$$D=\sqrt{d^2+4dh} \text{ for } d/r=20 \text{ or more.}$$

$$=\sqrt{d^2+4dh}-0.5r \text{ when } d/r \text{ is between 15 and 20.}$$

$$=\sqrt{d^2+4dh}-r \text{ when } d/r \text{ is between 10 and 15.}$$

If wall thickness is not equal to bottom thickness T which is also the blank thickness, volumes before and after drawing are equated and

$$D=\sqrt{d^2+4dh\cdot\frac{t}{T}}$$

To find a blank diameter for a shell of irregular cross section equate the weight before and after when a sample is available then

$$D=1.1284\sqrt{\frac{W}{wT}}$$

Where W=weight of the finished shell

w=weight of metal per cubic inch.

T=thickness of blank.

2. **Number of Draws :**

If D is the blank diameter and d is the shell diameter percentage reduction is$=\frac{D-d}{D}\times 100$. The greater the difference between blank and shell diameters. greater the area that must be made to flow and therefore higher the stress required to make it. Similarly as the ratio of metal thinkness T to the blank diameter (T/D) decreases, tendency to wrinking increases. Both the factors limit the reduction percentage. Top limit for the first draw is between 45 and 48% reduction. It is 30% for second draw and 20% for third and subsequent draws. Total reduction should not increase 70 to 75% when it should be annealed and reduction may again start at the maximum percentage. Number of draws does not exceed 3 to 4 in this way.

3. **Pressures :**

On various types of drawing operations the maximum pressure required is given by

$P=\pi.d.t.S.$

where d is inside dia. of the shall+one thickness of the shell.

t is the wall thickness of the shell

and S is the ultimate tensile strength of the material.

from the draw punch and some sort of ejector then ejects the shell from the die.

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r is the corner radius

h is height of the shell

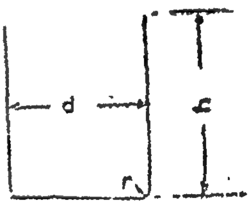

Fig. 15.30

then for thin shells where wall thickness t=bottom thickness T

$$D=\sqrt{d^2+4dh} \text{ for } d/r=20 \text{ or more.}$$

$$=\sqrt{d^2+4dh}-0.5r \text{ when } d/r \text{ is between 15 and 20.}$$

$$=\sqrt{d^2+4dh}-r \text{ when } d/r \text{ is between 10 and 15.}$$

If wall thickness is not equal to bottom thickness T which is also the blank thickness, volumes before and after drawing are equated and

$$D=\sqrt{d^2+4dh\cdot\frac{t}{T}}$$

To find a blank diameter for a shell of irregular cross section equate the weight before and after when a sample is available then

$$D=1.1284\sqrt{\frac{W}{wT}}$$

Where W=weight of the finished shell

w=weight of metal per cubic inch.

T=thickness of blank.

2. Number of Draws :

If D is the blank diameter and d is the shell diameter percentage reduction is $=\frac{D-d}{D}\times 100$. The greater the difference between blank and shell diameters. greater the area that must be made to flow and therefore higher the stress required to make it. Similarly as the ratio of metal thinkness T to the blank diameter (T/D) decreases, tendency to wrinking increases. Both the factors limit the reduction percentage. Top limit for the first draw is between 45 and 48% reduction. It is 30% for second draw and 20% for third and subsequent draws. Total reduction should not increase 70 to 75% when it should be annealed and reduction may again start at the maximum percentage. Number of draws does not exceed 3 to 4 in this way.

3. Pressures :

On various types of drawing operations the maximum pressure required is given by

$$P=\pi.d.t.S.$$

where d is inside dia. of the shall+one thickness of the shell.

t is the wall thickness of the shell

and S is the ultimate tensile strength of the material.

from the draw punch and some sort of ejector then ejects the shell from the die.

For single action presses a push through die simply employs a long nest to properly locate the redrawn shell and does not use a pilot or blank holder. For inverted dies in single action presses, a draw sleeve whose outside diameter is close fit in the predrawn shell is mounted round the draw punch on springs within the bed. In operation, the predrawn shell is located over the drow sleeve. The descending die draws the shell over the draw punch depressing the draw sleeve round the punch. Both knock out in the die and draw sleeve bring the drawn shell out.

Drawing Die Design Considerations :

So far sketches of various types of drawing dies have been given to make tool designer familiar and to enable him to choose a design. While giving dimensions to the die and punch the various factors that demand expert knowledge are the following :

1. Calculation of blank diameter :—Fig. 15.30

If D is the blank diameter

d is the shell diameter

r is the corner radius

h is height of the shell

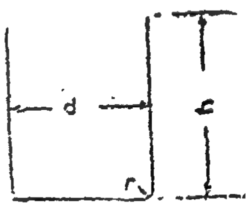

Fig. 15.30

then for thin shells where wall thickness t=bottom thickness T

$$D=\sqrt{d^2+4dh} \text{ for } d/r=20 \text{ or more.}$$

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$$=\sqrt{d^2+4dh}-r \text{ when } d/r \text{ is between 10 and 15.}$$

If wall thickness is not equal to bottom thickness T which is also the blank thickness. volumes before and after drawing are equated and

$$D=\sqrt{d^2+4d\ldots}$$ [illegible]

To find a blank diameter for a sh[illegible] [illegible]
equate the weight before and after [illegible]

$$D=1.1284\sqrt{\frac{W}{wT}}$$

Where W=weight of the finished shell

w=weight of metal per cubic inch.

T=thickness of blank.

2. Number of Draws :

If D is the blank diameter and d is the shell diameter percentage reduction is$=\frac{D-d}{D}\times 100$. The greater the difference between blank and shell diameters, greater the [illegible] must be made to flow and therefore higher the stress [illegible]. Similarly as the ratio of metal thickness T to the blank diameter D decreases, tendency to wrinking increases. Both the factors limit the reduction percentage. Top limit for the first draw is between 45 and 48% reduction. It is 30% for second draw and [illegible]% for third and subsequent draws. Total reduction should not increase 70 to 75% when it should be annealed and reduction may again start at the maximum percentage. Number of draws does not exceed 3 to 4 in this way.

3. Pressures :

On various types of drawing operations the maximum pressure required is given by

$$P=\pi.d.t.S.$$

where d is inside dia. of the shell + one thickness of the shell.

t is the wall thickness of the shell
and S is the ultimate tensile strength of the material.

The amount of blank holder pressure required to prevent wrinkles is about $\frac{1}{3}$ of the drawing pressure. In single action press the capacity of the press is determined by adding the drawing pressure and blank holder pressure. In double action press the two need not be added.

4. **Clearance Allowance :** Clearance is the difference between die and punch diameters. Adequate clearance must be left between sides of the punch and the die to avoid the possibility of the stock jamming in this area resulting in the bottom being pushed out of the shell. Clearance on cylindrical shell is $2\frac{1}{2}$ times stock thickness. On heavy nonductile stock which do not swell much at the compression limit total clearance is only twice the stock thickness or 2 mm more.

Clearance on redraws, more than twice the stock thickness is not necessary if the drawn shell is flangeless. However flanged shell may be provided a clearance more than twice the stock thickness. A table for draw clearance on one side only ($\frac{1}{2}$ of total clearance) is given in fundamentals of tool design by ASTME.

5. **Radius of draw Die :** The radius along the mouth of the opening is critical. Too small a radius increases the resistance to flow and may result in fracture of the material. Too large a die radius may permit wrinkles to be formed in the metal as it flows from beneath the blank holder into the die. For stock thicknesses upto 2 mm a radius of 3 to 4 times stock thickness is sufficient. For increasing thickness the radius increases from 6 to 10 times stock thickness. Optimum radii can be obtained by actual experiments.

6. **Punch Radius :** The radius around the lower edge of the punch also is critical. Inside radius is under compression and outside radius of the drawn shell is under tension. Too small a radius may increase the ultimate tensile strength and rupture may occur. By rule of thumb, the edge radius of the punch on the initial draw should be about 4 times stock thickness and reduced proportionately in succeeding draws.

7. **Venting :** Venting of punches and bottom forming pressure pads is quite important. Venting allows trapped air to escape and

provides passage for lubricants. Further it prevents suction between punch or pad and drawn work piece or shell.

Reverse Drawing :

Reverse redraws or turning work inside out are sometimes employed to effect a sharp reduction in cylinder diameter. In this type of tooling the shell is mounted upside down over a die block the outside diameter of which conforms to the inside diameter of the shell to be redrawn and inside diameter of which conforms to the desired outside diameter on the shell being drawn. The punch is mounted

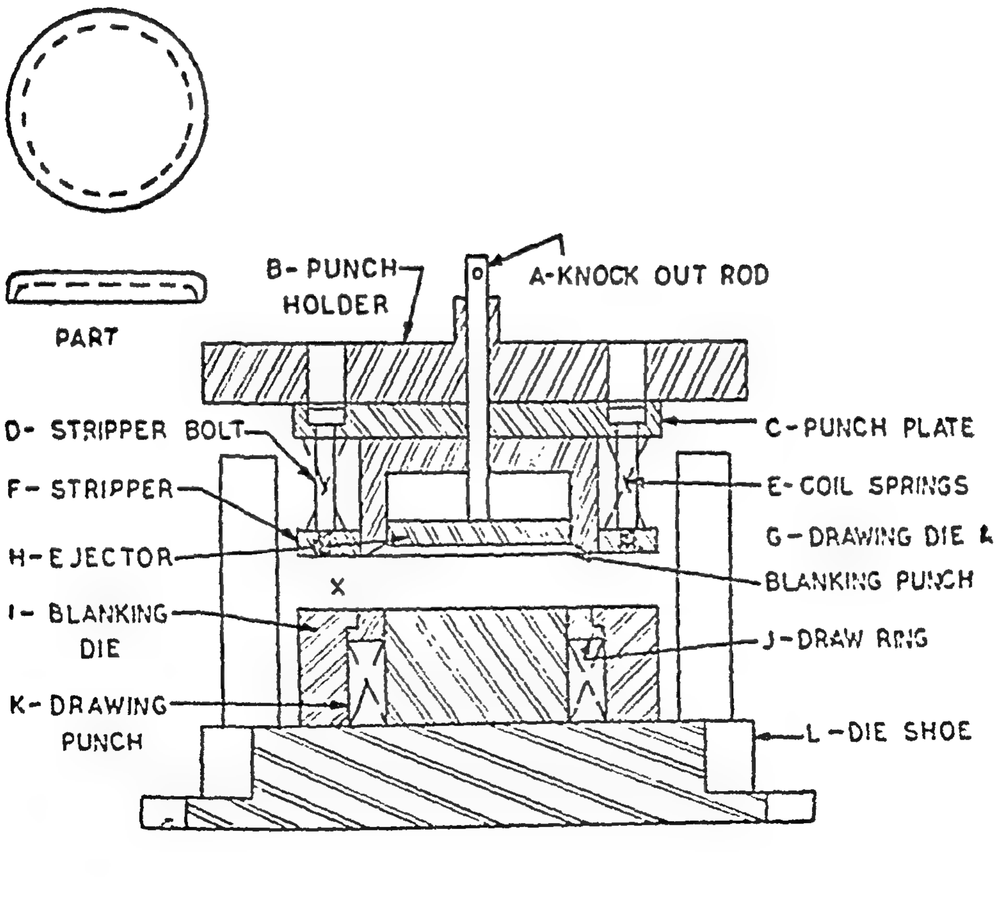

Fig. 15.31

QUIZ

1. What is the difference between a blanking die and a piercing die? What special precautions should be taken while designing piercing punch?
2. Explain the following with respect to blanking and piercing dies; clearance, angular clearance, shear on dies. What is the effect of each on size and shape of the cut blank?
3. What is optimum clearance? What is the effect of excessive clearance or too small clearance?
4. What is the difference between a progressive die, compound die and a combination die? Make sketches of each for a simple job.
5. What are the essential elements of a die? Explain the difference between a drop-through die and inverted die.
6. What is the function of a stripper? What are the various types of strippers in use in dies? How is knock out advantageous over a spring stripper?
7. List the various stock stops used in design of dies. What is the lead of die? How is it obtained in progressive dies?
8. Sketch the various ways of retaining piercing punches? What is back up plate? Where is it most used?
9. What is spring back and how is it controlled in bending dies?
10. What is the difference between bending, forming and drawing? Classify the dies used for each operation.
11. What are air bend dies? Why are they preferred over other type? Why should be the width of a die opening and why?
12. What is the field of application of a solid forming die and a block and pad forming die? Explain the essential elements of each.
13. Classify the drawing dies. What are the important considerations in drawing die design? How is deep drawing different from ordinary drawing?
14. What special design changes are necessary for secondary draw dies of both push through or inverted type? What is the function of pilot punch or draw sleeves in such dies?

PROBLEMS

1. Calculate the centre of pressure for the components shown in Fig. 15.32 and also find the blanking pressure in each case.

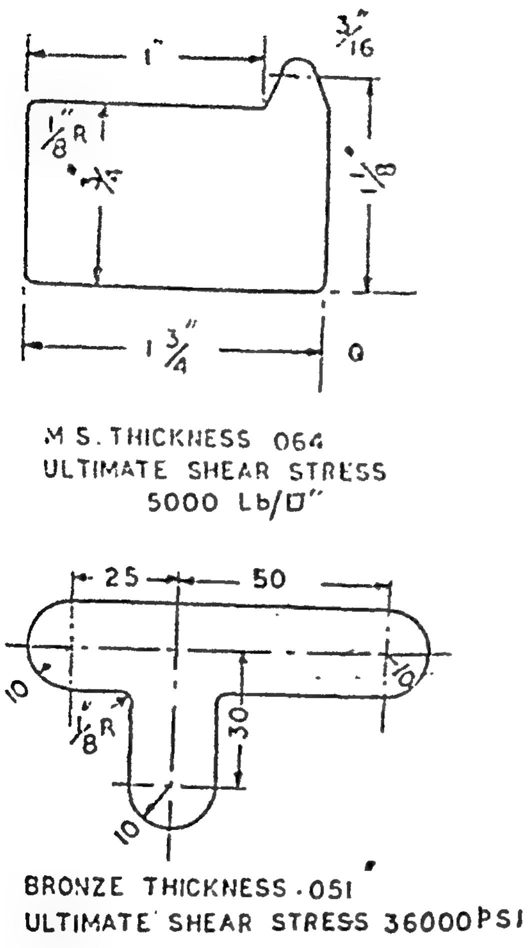

Fig. 15.32

2. Design blanking dies for the components Fig. 15.32 complete in all respects. Choose a die set if a strip atleast ¼" bigger in width than the length of two components is available. What will be the stock utilisation ?

3. Design either a compound or progresssive die for the component shown in Fig. 15.33.

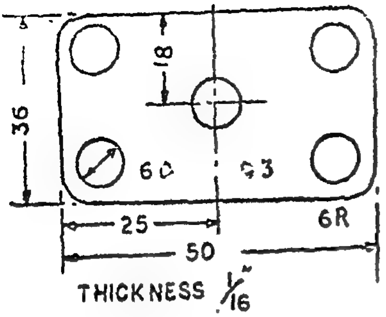

Fig. 15.33

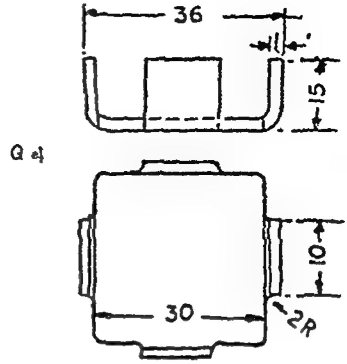

Fig. 15.34

4. Design a block and pad forming die for the component shown from a already prepared blank. Fig. 15.34
5. Design a combination blanking, piercing and drawing die for the component shown. Fig. 15.35.

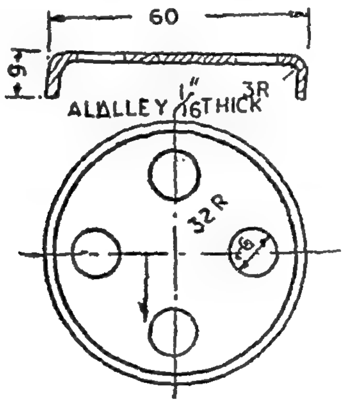

Fig. 15.35

6. A 18″ blank is to be drawn into a shell of 5″ diameter. Find out the reduction stages and sketch the drawing and redrawing dies.
7. Design a progressive die for the component, thickness 2mm in m.s.

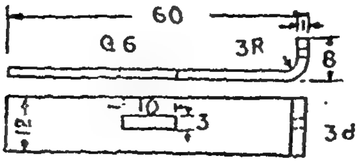

Fig. 15.36

CHAPTER XVI
FORGINING DIE DESIGN

Forging process imparts great strength to the blanks or forgings through the kneeding action on the hot metal as it is shaped between dies. By repeated blows of the drop hammer, the hot metal is made to fill the die cavities. Through this process of kneeding the metal showly and by stages in multi impression dies, a desired grain flow in the forging can be obtained. While designing forging dies the direction of grain flow lines in the finished forging is never forgotten. The grain flow in a rolled stock is straight but during forging it distorts but remains continuous in a sound forging design. While planning the impressions of a forging die, apart from other considerations, grain flow characteristics are of major importance. Kneeding increases the forging density and grain flow makes it fiberous.

STEPS IN FORGING DIE DESIGN

1. Calculation of blank size :

Forgings can be used as they are after cleaning etc. however most of the forgings require some type of machining whether it is drilling, turning or milling. Finished drawing only shows the component after all machining allowances have been removed in the machining stage. Hence as a step towards calculation of blank size, a forging drawing of the component is prepared showing the machining allowances on the component. The weight of such a forging is the net weight of the forging. Apart from the machining allowances other allowances are also added as either percentage of net weight or otherwise to reach at gross weight of a forging Other allowances to be added to net weight of forging to reach at gross weight are :

(a) Flash loss : The metal that comes between the flat surfaces of two dies after fitting the di ecavity in blanking impression is called flash. This extra metal is alround the forging at parting level of top and bottom dies. It may be assumed 25 mm wide and 3 mm

thick depending upon weight of the forging. Estimated circumference at the edges of the blanking impression multiplied by the cross section of the flash gives the volume of the flash. The weight can be calculated.

(*b*) **Scale Loss** : As the metal is being processed at high temperature the iron of the forging combines with atmospheric oxygen to form an oxide which is adhering over the forging as scale. The loss of metal in this way is about 6% of net weight of forging.

(*c*) **Tong loss** : The blank when processed is held with tongs at one end by the operator. The tong hold is about 1″ long and equal to bar stock. The tong hold is cut off in the final operation, however when calculating the blank size the weight of this is added to the net weight.

(*d*) **Sprue Loss** : The metal that is squeezed in the final finishing operation is still in contact with tong hold by a stretch of metal called sprue or runner or necking. In this portion the metal changes from circular to ellipjical towards the forging. Sprue loss is also $7\frac{1}{2}$ % of net weight.

(*e*) **Shear loss** : When several blanks are to be cut in a sawing machine then over all length of the bar stock is obtained by adding certain length which is lost to us as thickness of saw to each length of blank. Again the final blank out of a long bar may not be of exact length and is to be rejected. For finding out total bar stock length, the net weight of each blank is increased by about 6% of net weight.

Greatest section of forging gives the diameter of stock. Section of the forging may have to checked at several places to reach at a maximum diameter of forging.

$$\text{Length of the stock} = \frac{\text{Gross weight}}{\text{density of metal} \times \text{greatest cross section area}}$$

2. **Impressions in the forging die** : A forging can be completed in just one impression of a closed die of simple nature but may require several cavities or impressions for a complicated forging. First type of die is called a single impression die. Here the preliminary operations if any (like edging, bending, reducing) are carried out on other equipment. Second type of dies are called multiple impression dies. They contain all the impressions from the pre-

liminary to the finish impression in one set of dies and the forging process is carried out in one hammer only. Second step of forging design therefore consists in deciding about the number of impressions to be used in the die.

3. **Laying out of Impressions.** The various stages through which the forging is to pass are decided and they are laid out in die design drawing at appropriate places in the die block. The suitable spacing for each impression is made in the drawing and total space requirement is the die block size. Die block being of costly die material great judgement should be exercised in reaching at the size of the die block. Die block impressions and considerations in their design will be considered in the next article.

4. Sinking of the Die impressions : Dies for forging are blocks of steel having machined impressions in the shape of forging, to be made in them. Die block of dimensions determined from layout is chosen, either already hardened by manufacturers who are specialists in the field or it is in untreated state. Untreated block is easy to machine but presents difficulty of subsequent hardening because required skill and suitable furnace may not be available. Hardened blocks are difficult to machine but save the trouble of treatment. Die sinking in ordinary shop is done with the help of universal type machine tools like lathes, drills, shapers or milling machies. Big shops have special die sinking machines. A new method of die sinking is by spark erosion machining. Final finish impression is checked for size, shape and weight of the forging by closing the two halves and pouring liquid sulphur in it. The solid print is checked for approval. Only then flash and gutter are sunk round this impression.

Impressions in a multiple impression die :

Six type of impressions may be incorporated in a drop forging die for shaping the material progressively from bar form to the finished forging. They are

1. Fuller : This impression is required to reduce the cross section of a portion of the forging stock between the ends of the stock. Fuller also draws out the stock.

2. Edger or roller : This impression distributes the stock so that it will fill the next impression without excessive waste.

3. **Bender impression :** Bender impression is included in the die block when curves or angels in the forging make it necessary to bend the stock before it will fit properly in the finishing impression. Bending is a very important operation to keep the flow lines continuous in a job like crane hook.

4. **Blocking impression** or simply blocker gives the forging its general shape and allows the proper gradual flow of metal necessary to prevent laps and cold shuts. Blocking impression is of same contour as the finished part but the radii and fillets are large to permit the easiest flow of metal. A blocking impression is without a flush or gutter. All jobs may not require a blocking impression.

5. **The finisher impression :** This impression brings the forging to its final size. The finishing impression has both a gutter and flush impression cut round it to provide space for the excess metal. Both blocker and finisher have a necking or running impression so that the forging is still held with tongs.

6. **Cut off :** It is also part of the die block. It cuts the forging from the bar by cutting off the tong hold. The flash and gutter are however removed in separate trimming dies, under punch presses.

The faces of die blocks opposite to be impressions are made with dovetails and keyways for attaching them to the head of the ram and the anvil block. (fig. 16·01). Keyways must be so made that

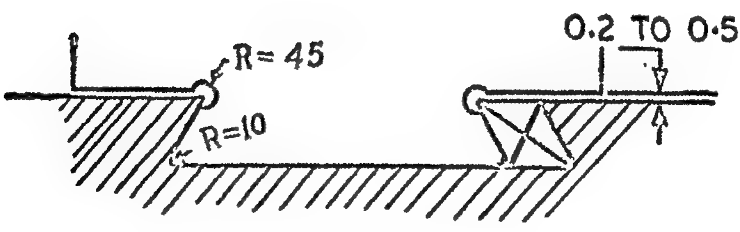

Fig. 16·01

they contact the entire surface of the dovetail. The grooves in the die holder and ram head together with the keys, prevent transverse displacement of die. The locking pins are used for preventing longitudinal displacement or shifting of the dies.

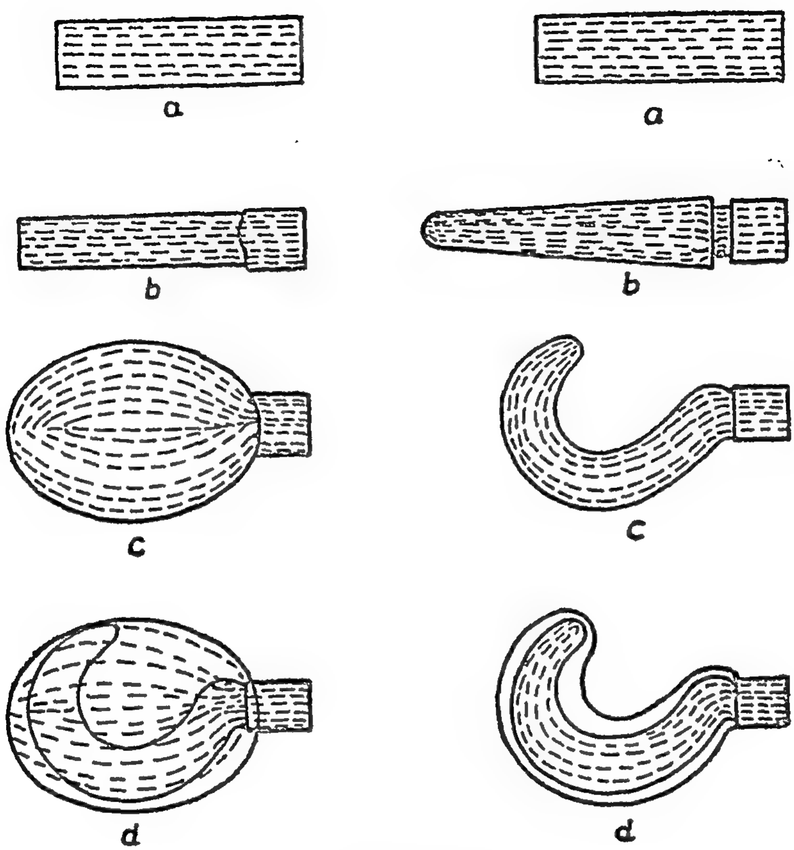

Fig. 16·02

B Gear blank :

A gear blank is made by upsetting certain length of a rolled stock. The rolled stock can be placed to the die with grain flow lines horizontally or by pointing the flow lines in the vertical direction. The blank placed with flow lines horizontally is shown in fig 16.03*a*. When the teeth are cut in the blank, the teeth at right angles to general flow direction will be very weak and will fail in impact. The flow lines in a blank upset from vertical direction flow of bar stock will have radial flow lines is shown in the figure 16.30*b*. In a gear prepared from this blank all the teeth will have radial flow lines. Such teeth will be very useful to take up impact loads.

lower dies converge towards the parting line. A cylindrical job need not be provided a draft on the circular portion but end faces are provided with a draft, fig. 16.05.

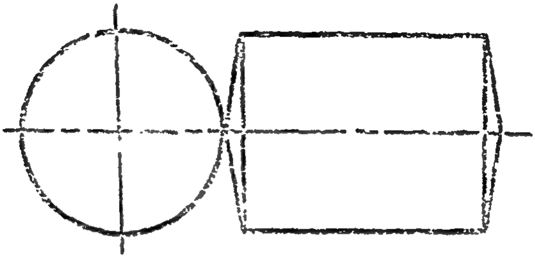

Fig. 16·05

3. **Parting lines :** Drop forging dies are made in two halves. The total thickness of a forging is thus sunk partly in top die and partly to lower die. When the dies close on a forging they create a parting line all round. Parting line is not always in the centre of forging thickness but depends upon the convenience of the designer.

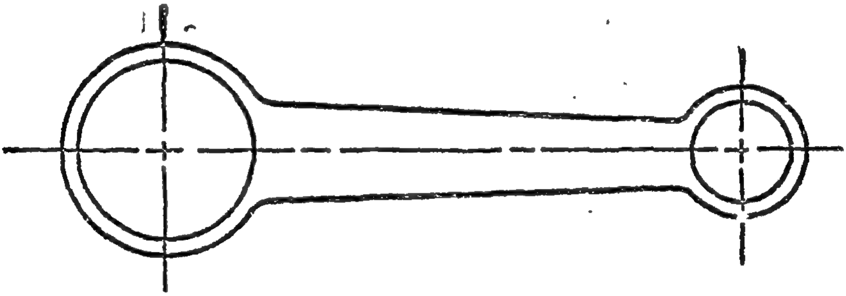

Fig. 16.06*a*

Fig. 16·06*b*

Fig. 16·06*c*

Forgings with horizontal parting planes and consequently the dies for them are more economical to produce but dies with multi-direction parting lines become more economical for certain type of forgings. Fig. 16.06*a* shows a crank arm which could be parted through the centre line *XX* but then draft would have to provided to faces of the two large bosses. This would add to weight and would make it difficult to drill it before milling when the requirement of the component does not require a milled face but a face as it is. Again after removing the stock from the die cavity, an operation of bending is also to be provided. Such a forging can be made by having a multidirectional parting line as in fig. 16.06*b* but such dies are always to be locked otherwise side thrust to one side will be more and there will be a tendency for the upper die to shift towards the direction of thrust. The thurst which had to go on to hammer guides is now taken up by the lock provide in the die. Sometimes the design of the die impression itself provides the locking arrangement as in *fig. 16.06c for the same component or the bending* operation is performed in the last after trimming in a bending die.

4. Fillets and Corners : Rounding of the apex of an internal angle is called a fillet where as the apex of an external angle is corner. Metal has to flow over the corners of the die to fill up the fillets of the die. Hence forging should be intially so designed that there are ample fillet radii and corner radii. The fillets and corners of the forging are produced by the corners and fillets metal to reach the fillets of the die the corner radii should be generous. A corner without ample radii may cause laps and misruns Therefore sharp corners whether external or internal should be avoided and the forging should be designed accordingly. Harmful effects of sharp corners can be.

1. Decreasing of die life due to excessive wear at sharp corners.
2. More number of blows to pass metal over the corners and to push it in the fillets of the die.
3. Stress concentration at sharp corners.

Fillet and corner radii tolerances are relative to the size of the forging. In general the minimum fillets and corner radii must not be less than 1·5 mm and preferably more.

5. **Shrinkage and Die wear :** As the metal is processed at high temperature (round about 1000 to 1130°C) it shrinks in dimension when the forging, so made, comes down to room temperature. To have forgings of correct dimensions at room temperature the die impression should be bigger in dimensions. Therefore while sinking dies, a shrink scale is used to finish impressions. For steel the shrinkage scale provides for a shrinkage of 10 mm per meter. However it is difficult to control the final size exactly by applying the shrinkage allowance from the scale. Size due to shrinkage may vary from ·01 to ·03 mm per mm of width or length on a given forging.

Shrinkage property of the forging forces the designer to have the cavity of the die large but the dimensions of a die cavity becomes larger automatically also due to die wear. The dimension of a die cavity should therefore be made little smaller, yet within the allowed tolerance so that even after wear over a period of time, the dies produce forgings within the + tolerance of forging dimensions. Die wear allowance ranging from 1 to 2 mm on external surfaces of forgings weighing up to 5 kg. is provided. On forging between 10 and 20 kg. this may increase from 1 mm to 3mm.

Mismatch

Unlocked dies with flat parting surfaces may not exactly align with each other giving rise to a forging defect called mismatch. The shifting of the dies may occur side ways or end ways. Any mismatch of forging should be removable in machining to give a forging of exact dimensions. Machining allowance on a forging should be more than expected mismatch or shifting. The allowable mismatch which can be accepted by the customer for a surface not to be machined is 0.30 mm for a forging upto 5 kg 0·50 mm for a forging from 5 to 10 kg. A 0.125 mm mismatch should be added for each additional 5 kg.

Tolerance :

Forging dimensions which cross the parting plane should fall within plus and minus tolerances, as to produce an exact dimension during forging process in drop forging is difficult. Commercial plus tolerance on thickness dimension *i.e.* across the parting plane are

1 mm on forgings up to 1 kg. 2 mmon forgings from 2 kg 10 kg and 3mm from 10 to 20 kg Negative tolerances are 0.12 mm upto one kg 0.5mm from 2 to 10 kg and 0.50 mm from 10 to 50 kg. Closer tolerances are obtained by coining the forgings. This consists of restricting the parts in a heavy duty mechanical press. It is possible to obtain tolerances on thickness dimensions within ±.12 mm and sometimes ±.05mm. The process of coining often results in eliminating machining operations.

6. **Machining allowance :** The surfaces which are to be finished by machining must be provided with sufficient machining allowance. The forgings so machined should be free from external defects caused during forging process. Machining allowance provided should be able to include any mismatch, scale pitting, or decarburation, minus thickness tolerance and shrinkage. Machining allowance is generally 0.5 mm per surface for one cm. diameter jobs.

7. **Web thickness :** The minimum web thickness should be approximately 3mm with a ± 5 mm tolerance. The flash thickness will generally range from 1.00 to 2.0 m. A die cavity deeper than diameter of the cavity is also not desireable. Flash impression should be sunk in both halves of the die where as gutter should be sunk in the upper die. It will enable the forging to sit flat in a trimming die.

1. *Flash and gutter sizes :* Both flash and gutter take the excess of metal from the finishing impression. The amount of flashing that must be provided varies from forging to forging. On steel the flash is provided as follows :

diameter in mm.	Thickness of flash in mm.	Width of flash in mm.
0—35	1.0	4
35—50	1.5	6
50—65	2.0	7
65—75	2.5	8

Depth of gutter varies from 3 to 6 mm. and width varies from 25 to 45 mm depending upon weight and size of forging.

9. *Size of Die block :* Length of the die block depends upon length of the forging Width of the die block is made up by adding the following :—

1. Fuller width=Diameter of bar stock.
2. Blocker width=widest part of the forging.
3. Finisher width=widest part of the forging.
4. Flash=gutter width.
5. Edger width=greatest section of forging.
6. Sum of distances, between fuller and blocker impression, between blocker and finisher gutter, between fishing gutter on the other side and edger.
7. Bender impression width if there be any.

In addition to the widths and length of forging, emperical data relating to minimum striking surface are necessary to establish the die block size.

Open and closed die forging :

Drop forging with the formation of flash is called open die forging. When the dies are so designed that no flash will be formed it is called closed die forging. The volume of metal for closed die must be accurately calculated. Open die forging is more commonly practised than forging in closed dies, the latter being practised for producing forgings upto to 100 kg. in weight whereas forgings up to one ton can be produced by the open die method. Open die drop forgings are produced in hammers and presses while closed die forgings are made in forging presses and horizontal forging machines and more rarely on drop forging hammers.

Material of dies blocks :

For large scale production dies of forged carbon or alloy steel are employed exclusively. Carbon steel dies are employed for the production of a comparatively small quantity of forgings, alloy steel dies are generally used for large scale production of forgings. The most commonly used die steels are. chromium, nickle, chromium molybdenum, chromium titanium, and chromium-tungsten steels. Die impressions in the blocks are sunk in die sinking machines. They are hardened after finishing the impression. Hardened blocks are also available in the market.

Manufacture of die blocks with insert dies is becoming more popular these days. These are much cheaper than dies made out of solid blocks. Die blocks may be made of carbon steels where as

inserts only are made of alloy steel. Inserts can be easily replaced when worn out. One die block can suit any number of inserts.

QUIZ

1. List the various losses that must be considered in determining the blank size of a forging ?
2. How will you proceed for designing a die for a forging ?
3. Describe the procedure for reaching at a value of ; flash loss, scale loss, tong loss and sprue loss ?
4. List the impression of a multi-impression die. What should be width of fuller and edger ?
5. Why is bending operation sometimes essential for making components by forging process ?
6. What is the difference between a blocking impression and finishing impression ?
7. Describe the importance of keeping grain flow lines continuous in a crane hook forging ?
8. What precaution is necessary while upsetting a rolled stock blank for gear manufacturing as regards flow lines ?
9. What are necessary considerations that must be cared for, while designing dies for drop forging ?
10. When should you provide a locking arrangement to the dies ?
11. Why is draft necessary in forgings also ? What should be value of draft both external and internal ?
12. What constitutes the width of a die block ? Why should gutter be in the upper die block only ?
13. A connecting rod of suitable dimensions is to be manufactured in a drop forging hammer. Find the dimensions of the bar stock and describe the various impressions of the multiple impression die. Prepare a layout sketch of the die block and complete its overall size.

CHAPTER XVII

DESIGN OF SINGLE POINT CUTTING TOOL

The work of a tool, designer consists of following steps :

(*i*) Determining the forces acting on the cuting surfaces of the tool and determining the optimum tool geometry.

(*ii*) Finding the most producible shapes of the cutting tool and determining the tolerances on the dimensions of the cutting and mounting elements of the tools.

(*iii*) Calculating the rigidity of the cutting and mounting elements of the tool.

(*iv*) Making a working drawing of the tool and computing the manufacturing dimensions.

17.1. Rigidity considerations for a single point turning tool.

The shank of a single point tool may be rectangular, square or round in section. The rectangular cross-section is the most popular as reduction in its strength is much less when a seat is cut into it for

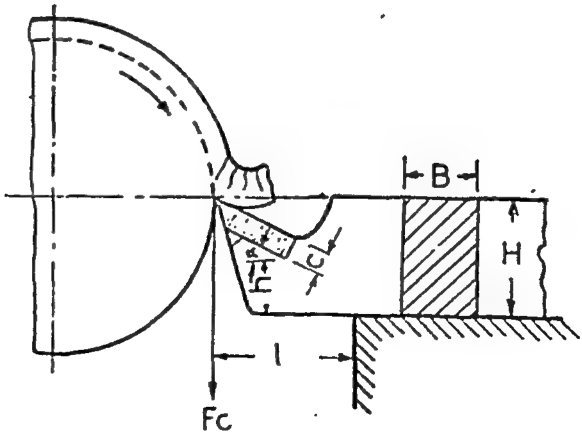

Fig. 17.1

the tip. In most of the cases (Fig. 17.1) H/B varies between 1.25 to 1.6. It is desirable to use tools having H/B = 1.6 for semifinishing and finishing operations and those with H/B = 1.25 for roughing. Square shank tools are used for boring turret and automatic lathes. Round shank tools are used for boring and thread cutting.

The permissible size of the shank crossection is determined on the strength basis. For this purpose the actual bending moment (M_b) acting on the tool is equated to the moment of resistance of the tool shank (M'_b)

i.e. $$M_b = M'_b \quad ...(1)$$

From fig. 17.1

$$M_b = F_c . l \quad ...(2)$$

$$M'_b = \rho Z \quad ...(3)$$

Where l=tool overhang (mm)

ρ=permissible bending stress of the shank materials. For unhardened steel having tensile strength in the range of 60—70 kg/mm², ρ=20 kg/mm².

Z=Section Modulus of the tool shank (mm³)

For rectangular cross-section $Z = \frac{BH^2}{6}$

For circular cross-section of diameter d (mm)

$$Z = \frac{\pi d^3}{32}$$

Hence substituting from (2) and (3) into (1) we have for a rectangular cross-section tool holder

$$F_c l = \frac{BH^2}{6} \rho \quad ...(4)$$

or $$BH^2 = \frac{6F_c l}{\rho} \quad ...(5)$$

Taking H/B=1.6, we get

$$\underset{(mm)}{B} = \sqrt[3]{\frac{6F_c l}{2.56\,\rho}} \quad ...(6)$$

CHAPTER XVII

DESIGN OF SINGLE POINT CUTTING TOOL

The work of a tool, designer consists of following steps :

(*i*) Determining the forces acting on the cuting surfaces of the tool and determining the optimum tool geometry.

(*ii*) Finding the most producible shapes of the cutting tool and determining the tolerances on the dimensions of the cutting and mounting elements of the tools.

(*iii*) Calculating the rigidity of the cutting and mounting elements of the tool.

(*iv*) Making a working drawing of the tool and computing the manufacturing dimensions.

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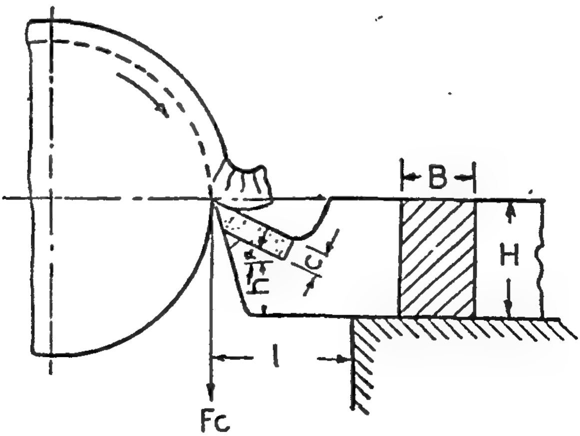

Fig. 17.1

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Taking H/B=1.6, we get

$$\underset{(mm)}{B} = \sqrt[3]{\frac{6F_c l}{2.56 \rho}} \quad (6)$$

Similarly for a square shank

$$\underset{(mm)}{B} = \sqrt[3]{\frac{6F_c l}{\rho}} \qquad \ldots(7)$$

and for a circular shank

$$\underset{(mm)}{d} = \sqrt[3]{\frac{32F_c l}{\pi \ P}} \qquad \ldots(8)$$

The tool overhang l is usually taken as (1—1.5) H.

The tool crossectional area calculated on the basis of the permissible bending stress is not sufficient. The maximum deflection which the tool undergoes during the machining operation should also be limited.

The maximum deflection of the tool would occur at the cutting point and could be found by assuming the tool shank to be a cantilever loaded at the free end. For a tool having rectangular cross-section the deflection δ of the tool point is then given by

$$\delta = \frac{4F_c l^3}{E\ BH^3} \qquad \ldots(9)$$

where E is the Young's Modulus,

The deflection 'δ' would directly govern the natural frequency of vibration of the tool (eqn. 10.) If this frequency of vibration happens to concide with the frequency of cutting chatter would result. Under all circumstances chatter should be eliminated as this leads to poor surface, poor tool life and may also damage the machine tool itself.

The natural frequency of vibration of a cantilever (ω) having a deflection δ(mm) at the free end is given by

$$\omega = \frac{0.625}{\sqrt{\delta}} c/s \qquad \ldots(10)$$

17.2. Carbide tipped single point tools :

Carbide tipped tools can be classed as

(*a*) Tip brazed to the shank.
(*b*) Mechanically held tips.

(*a*) **Tip brazed to the shank :**

The carbide tip can be brazed directly to the shank of the tool. The tools have to be heated for this purpose in a gas furnace or by induction heating. The brazing filler material may either be electrolytic copper or an alloy of brass with 5% each of nickel and ferromangnese. The thickness of the filler material layer in the brazed point should be approximately 0.1 mm.

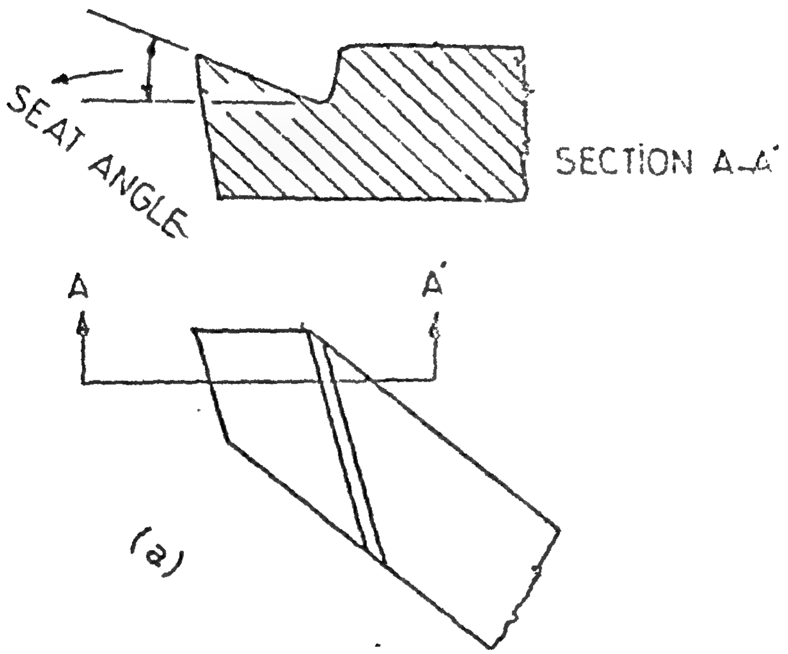


Fig. 17.2 (*a*)

In order to facilitate brazing the tool shank has to be provided with a seat. Some of the common types of seats are shown in figs. 17.2 (a). (b) It is a good practice to make the seat angle equal to $\alpha+5^\circ$ where α is the tool rake angle and for strength. It should also be checked that $h \leqslant 2/H$ (Fig. 18.1). The tip thickness t_c is mainly selected on the consideration of strength and the permissible number of tool regrinds, which can be had. For heavy cutting a thicker tip is preferable.

18.3. Tools having Mechanically clamped tips :

Brazing the tool tip to the shank has got certain disadvantages. Sometimes cracks appear within the carbide tip. This is due to non-

uniform cooling of the tip and also due to difference in the coefficients of thermal expansion of the carbide and the shank material. In addition scales are formed on the carbide tip during brazing. Mechanically clamped tips overcome these defects of the brazed tip tools and also reduce the cost of manufacture. Hence they are more popular. Some of the typical methods for clamping the tool bit to the shank are shown in fig. 17.3, 17.4 and 17.5.

Table I also compares the machining cost obtained with brazed and clamped tools.

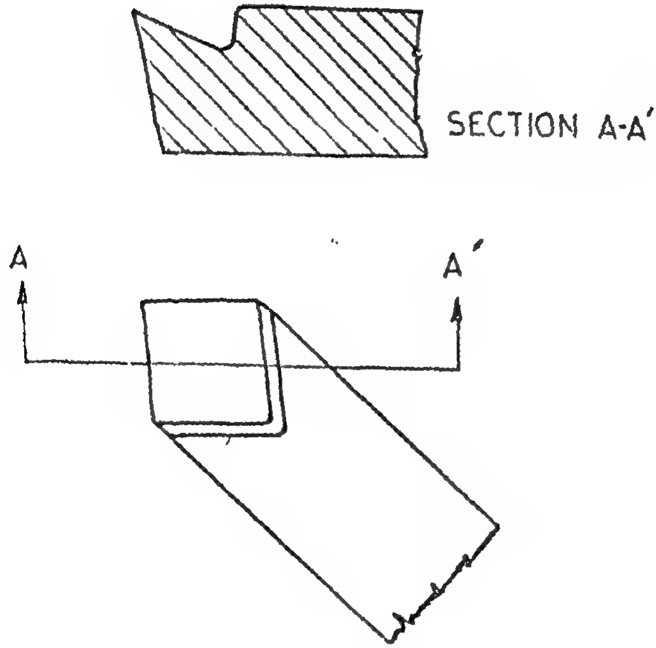


Fig. 17·2 (*b*)

Table I

Particulars	Throw away tool	Brazed tool
Brazed Tool		
Purchase cost Rs. 25.00 each		
No of regrinds possible 10		
Tool cost per cutting edge......Rs.		2.28
Clamped Tool		
Cost of each tip......Rs. 6·00		
No. of cutting edge per tip 6		
Tool tip cost per edge	1.0	
Holder for the throw-away tip.. Rs. 76.00		
No. of cutting edges per holder.. 400		
holder cost per cutting edge...Rs.	0.19	
Regrinding Cost		
Tool regrinding labour rate Rs. 15.00/hr.		
Grinding time per edge...10.0 min.		
Grinding cost per tool edge...Rs.		2.50
Tool setting cost		
Tool setting cost per hr. . Rs. 15.00		
Tool setting time per tool edge ..	5 min	1 min
Setting cost/cutting edge, Rs......	0.25	1.25
Total cost per cutting edge, Rs.	1.44	6.03

17.3. Design of chip breakers :

Importance of chip breakers has already been discussed in chapter five. The types of chip breaking methods commonly employed are by the use of (*i*) groove type chip breakers or (*ii*) clamped type chip breakess or (*iii*) Dynamic chip breakers.

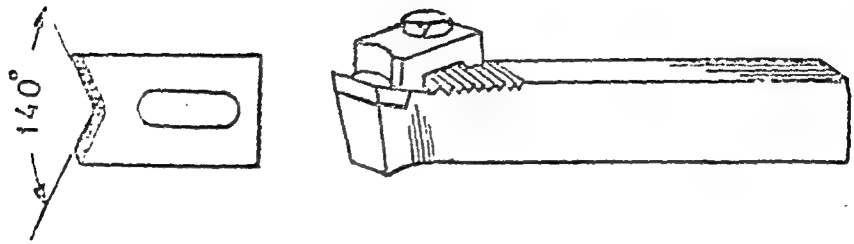


Fig. 17.3

17.3. 1. Groove type chip breakers :

Grooves or steps formed on the tool face would act as an obstruction to the chip flow and hence would result in excessive

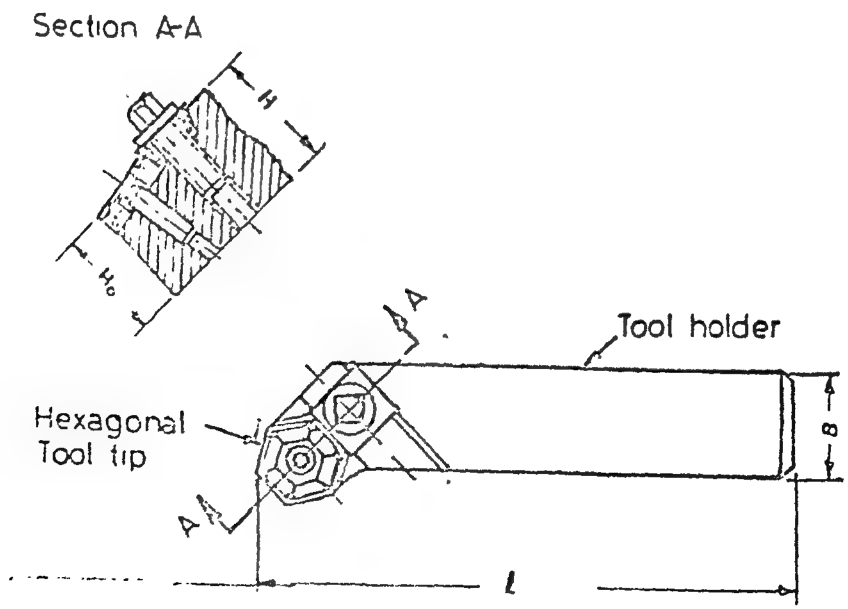


Fig. 17.4

curling leading to the fracture of the chips. The usual diamensions of the chip breaker groove. Recommended for the single point carbide tools is shown in fig. 17.6. Such grooves have proved to be successful in operations like turning, boring, facing etc. under wide range of working condition.

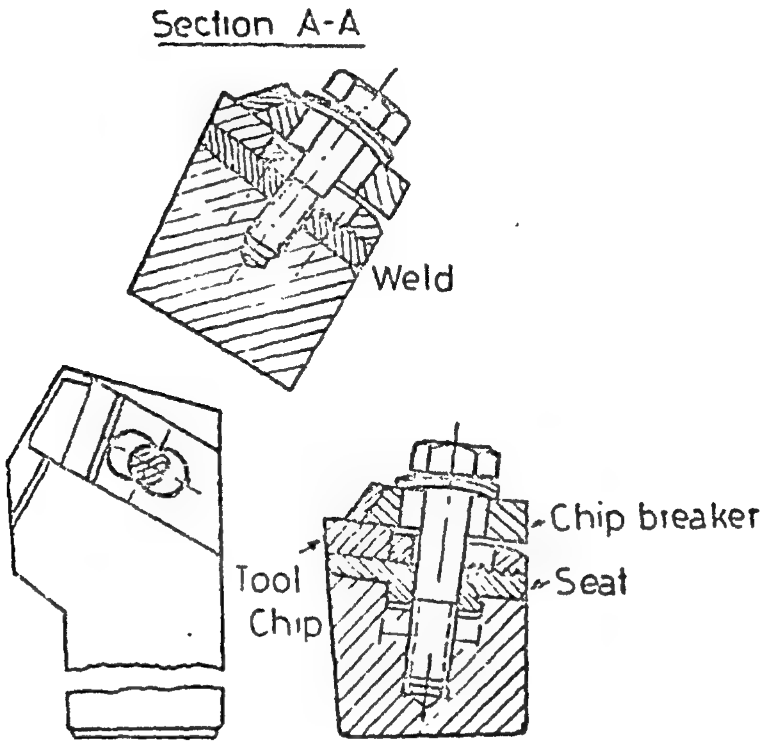


Fig. 17.5

The optimum size of the groove depends upon the work material and the cutting conditions employed. However, this method of chip breaking suffers from the following two disadvantages :

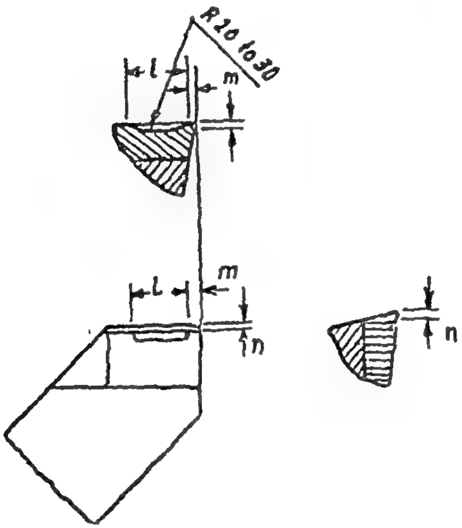
(*i*) Grinding of the grooves is expensive.

(*ii*) The grooves size has to be altered with a change in the cutting conditions.

The former objection could be overcome by providing the groove during sintering of the tool bits. Whereas the latter defect could only be overcome by the use of adjustable types chip breakers.

17.3.2. Adjustable or clamped chip breakers :

Adjustable type chip breaker is shown in fig. 17.5. The chip breaker has been found to work efficiently in steel turning whilst employing a depth of cut between 110 mm. feed ranging between 0 08 to 2 mm/rev and speed varying between 50 - 600 m. per min. The chip breakers are usually made of high strength steel often hardend and ground or faced with stellite to give increased hardness.



Typical dimensions of the chip breaker groove whilst turning structural steel with tungsten carbide tools.

n=0.1—0.2 mm. less than the feed rate for feed $\leqslant$ 0.6 mm/cl.

n=feed for feed $>$0.6 mm./rev.

n=0.1—0.6 mm.

l=width of the chip+0.5—1.5 mm.

Fig. 17.6

17.3.3. Dynamic chip breaking :

Chips can also be broken into short pieces by oscillating the tool in the feed direction at a controlled frequency and amplitude.

This method of chip breaking is still in experimental stage but has proved to be advantageous owing to the ease of adjustment for varied cutting conditions.

17.4 Designing and applying tools for interrupted cuts.

When interrupted cuts are to be taken with a single point carbide tool the following precautions be observed.

(1) Use largest possible shank size. For internal cutting use carbide shanks instead of usual carbon steel shanks. This would improve the rigidity of the tool.

(2) Use tough, shock-resistant carbide grade.

(3) Use thicker tips than would normally be used for continuous cutting.

(4) Use largest nose radius possible.

(5) Use large side cutting edge angle and minimum end cutting edge angle.

(6) Use minimum relief and clearance angle to give the cutting edge maximum support.

(7) When conditions permit use negative rake tools.

(8) If possible design or apply the tool so that the interruption contacts the rake surface back of the nose (see fig. 17.7).

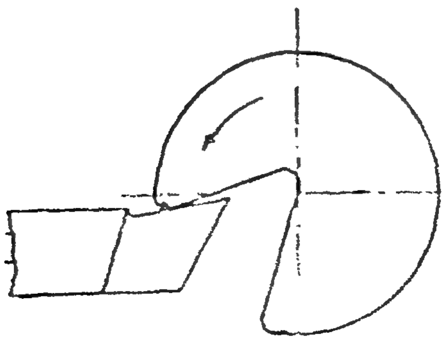
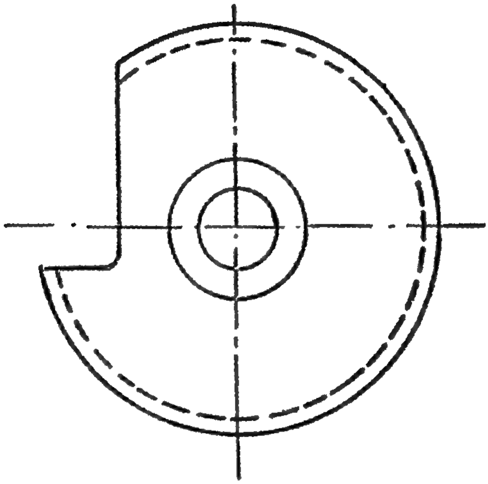


Fig. 17·7

(9) Keep the tool overhang to a minimum.

(10) Make everything in the set up as rigid as possible.

(11) For steel machining hone the cutting edge heavily.



(a)

Fig. 17.8 *a*

18·5. Form Tools :

In turning operation a form tool can produce the desired contour on the work piece. Use of such a tool ensures high output, accurate dimensions and uniformity of the work produced. Such types of tools are common in mass production. The form tool can be :

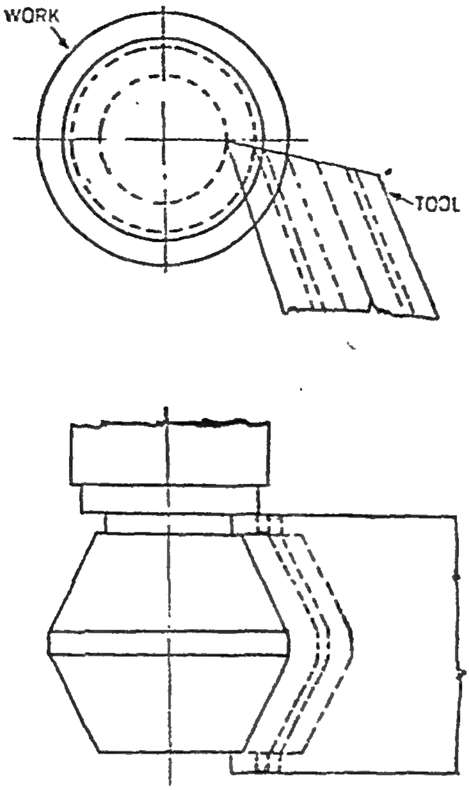
Circular form tool (Pig. 17.8 *a*).

Radial feed flat from tool (Fig. 17.8 *b*).

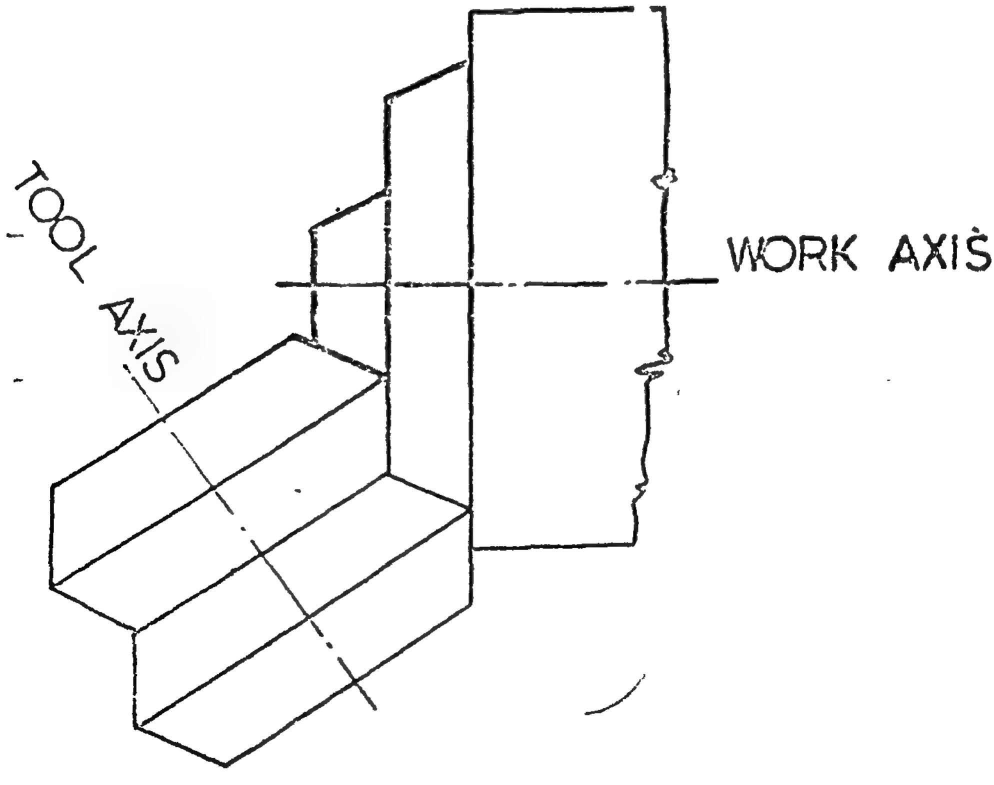
End form tool (Fig. 17.8 *c*).

tangential tool (Fig. 17.8 *d*).

Most form tools are made of H.S.S. but carbides are also becoming popular as a form tool material. The carbide form tools

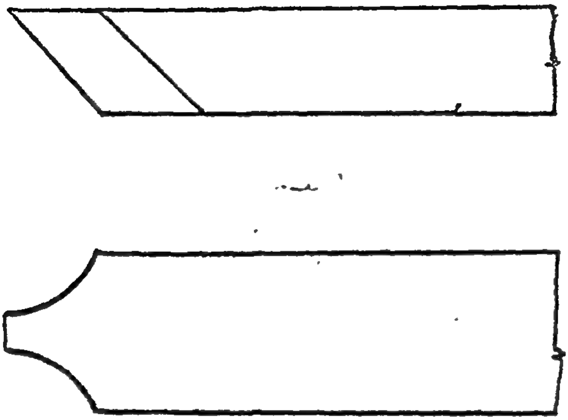


(b)
Fig. 17.8 *b*



(c)
Fig. 17.8 *c*

like turning tools can either be brazed or damped. A form tool should be provided with proper rake and relief angles. Table II shows the recommended angles for the form tools.



(d)

Fig. 17·8 *d*

Table II

Material	BHN	Rake angle deg. (α)
Mild steel	upto 150	25
Hard steel	235—290	12—20
Soft C.I.	upto 150	15
Aluminium	...	20—25

The clearance angle depends upon the type of form tool. It usually varies between 10—15°.

18.5.1. Determining the profile of the form tool.

(*a*) Outside diameter of the circular form tool having positive rake angle.

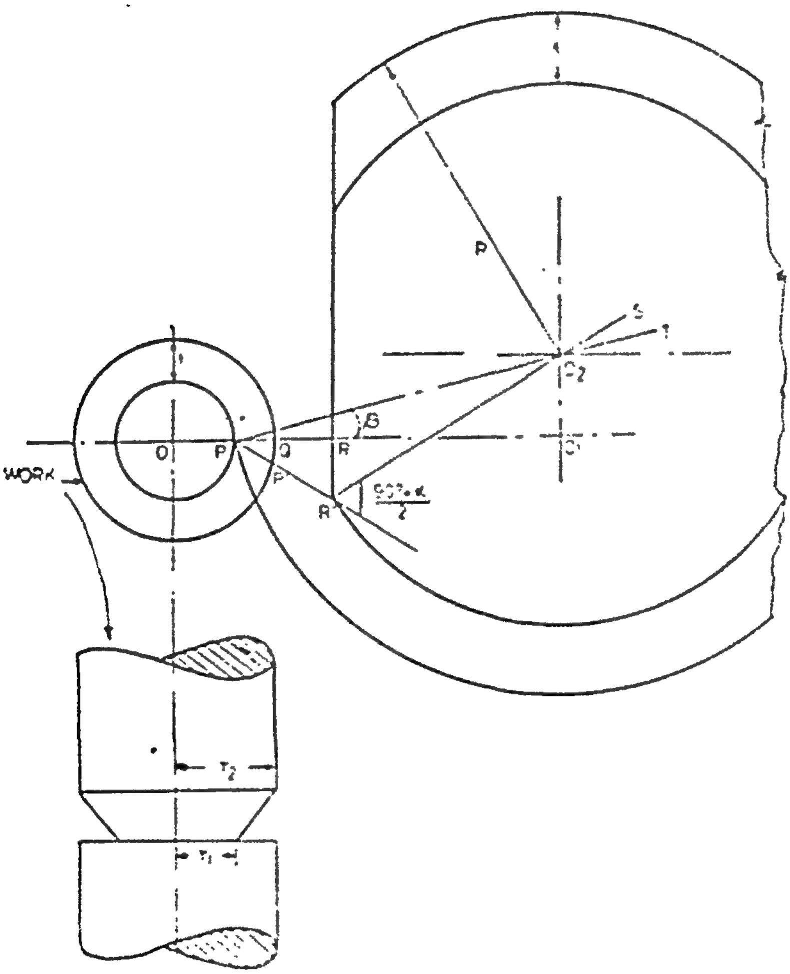


Fig. 17.9

Fig. 17.9 shows a job which has to be produced by means of a circular form tool. It is required to determine the radius R of the tool. In order to determine R a graphical method has been described here.

Through the point P we draw a line PR′ at an angle "α" the tool rake angle. The horizontal distance QR is set depending upon the chip-flow considerations (usually between 3-12 mm.). R′ is vertically below R and is determined by the intersection of PR′ and the vertical line RR′. In order to determine the centre O_2 of the form tool another line PO_2 inclined at an angle equal to the tool clearance angle β is drawn In order to locate the centre O_2 of the form tool, through the point R′ a line $R'O_2S$ is drawn inclined at an angle $\frac{90+\alpha}{2}$ with respect to the tool face, the intersection of the lines $R'O_2S$ and PO_2T determines the centre O_2. Having known O_2 the tool radius R can be determined.

(*b*) **Profile of the form tool :**

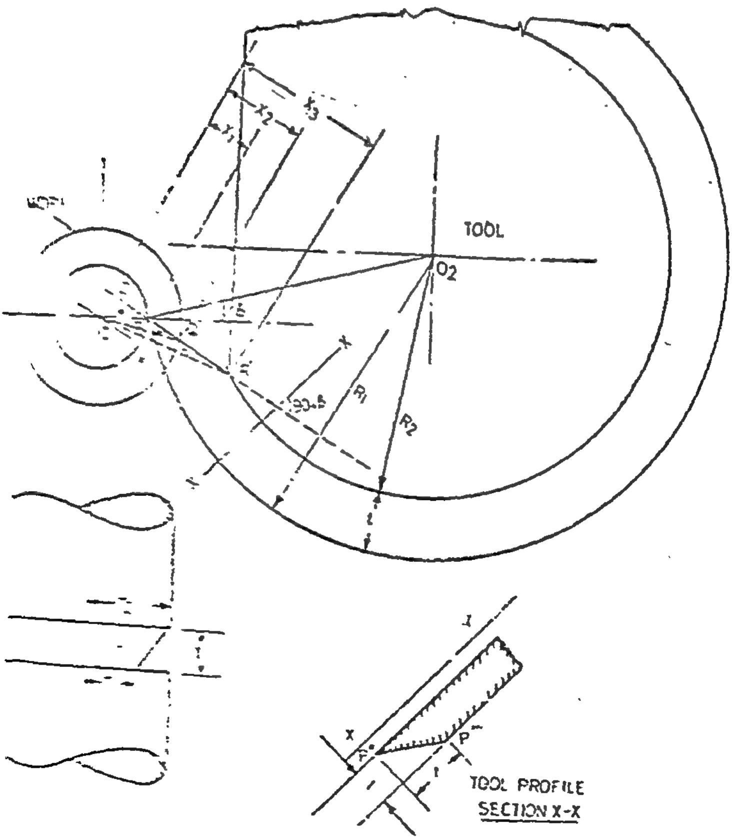


Fig. 17.10

For the work shown in fig. 17.10 let it be required to determine the profile of the form tool. The first step in this direction would be to determine the radius R of the form tool and the position of its centre O_2 as described in the previous section. Connecting the points PP′R′ etc. to the centre O_2 we get a series of right angled triangles such as POO_1, $P'OO_1$, etc.

In the $\triangle POO_1$, we have $X_1 = r_1 \cos \alpha$

In the $\triangle P'OO_1$, we have $X_2 = r_2 \cos \alpha_1$

where $$\sin \alpha_1 = \frac{r_1 \sin \alpha}{r_2}.$$

Calculations are usually made for a large number of points on the line PP′R′ and calculating the dimensions X_1, X_2, X_3.........etc. in the manner described above.

To construct the tool profile in the radial direction draw the radial line XX and measure the dimension "t" perpendicular to the line XX the dimension t is equal to $(R_1 - R_2)$ which fixes the tool profile in the radial direction.

18.6. Design of milling cutters :

Milling is comparatively faster method of metal removal than is possible with single point cutting tools. The reason being multiple number of cutting teeth and intermittent nature of the tool work contact. Like a single point tool the milling cutters are also provided with the various cutting angles. The various angles for two types of milling cutters are shown in fig. 1.13.

Helix angle. All milling cutters in practice have their teeth set along a helical path. For light cuts helix angle of 15° is quite common but for heavy duty work helix angle in the range of 45–50° is more common.

Number of teeth (N) :

For HSS cutter above 3 in diameter (75 mm.) N is given by

$$N = 2D + 8 \quad \ldots(11)$$

D = cutter diameter in inches.

Some times for helical mills the number of teeth could be obtained by the relation

$$N=\frac{12.56\,D}{D+4d}\cos P \qquad \ldots(12)$$

P=helix angle

d=depth of cut

For cutters having carbide inserts the number of teeth (N) could be calculated by

$$N=\frac{KH}{Jndw} \qquad \ldots(13)$$

K=constant its value depends upon the work material.

K=1.5 for C.I.

K=2.5 for Aluminium

K=0.65 for Steel

H=H P. used in cutting

n=cutter speed r.p,m.

w=width of cut in inches

In general the cutter should be designed that not more than two teeth are engaged in cutting at any time. The commonly employed cutter angles used in milling are given in the table.

Table

Rake Angles for Milling Cutters.

Work Material	H.S S. cutters	Cast alloy cutters	Carbide cutters	Relief angle, deg.
	Radial rake deg.	Radial rake deg.	Radial rake deg.	
Soft CI	10—15	6—8	3—6	4—7
Hard CI	10	3—6	0—3	
MS	10—15	3—6	0—(—5)	3—5
Al alloys	20—35	10—15	10—20	10—12

CHAPTER XVIII

STANDARDS OF MEASUREMENT

The earliest method used for measuring the dimensons of a given component consisted in comparing its dimension with a known standard. This concept of measurement has not changed eversince. However, progress has been made at the International level, towards adopting an uniform standard for measurement. Two widely used standards are

1. International standard metre
2. Imperial standard yard.

18.01. INTERNATIONAL STANDARD METRE

This standard in its present form was set up in the year 1872. Standard metre is made of a platinum—iridium alloy bar having a crossection as shown in fig. 18·1. The upper surface of the web is highly polished and has two fine lines engraved over it. The distance between these two lines when measured at a temperature of 0°C has been taken to be one metre. The International standard metre is maintained by the International Bureau of Weights and Measures in France.

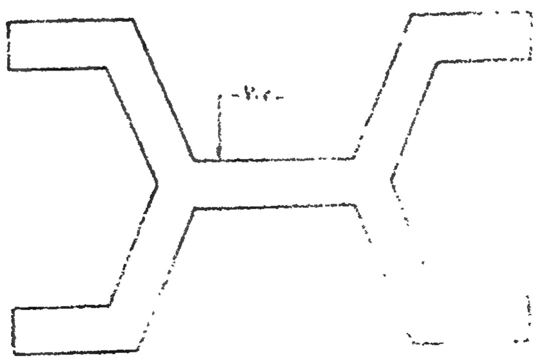


Fig. 18·1 Crossection of International Standard Meter

18.02 IMPERIAL STANDARD YARD

The Yard in its current form was first set up in 1855. It is made of 1 in x 1 in section bronze bar 38 in long. The bar has two, $\frac{1}{2}''$ diameter $\times \frac{1}{2}''$ deep holes (fig 18.2) Each of the holes are fitted with $\frac{1}{10}$ in diameter gold plugs. The top surface of these plugs lie on the neutral axis of the bronze bar. The uppermost surfaces of the gold plugs are highly polished and contain three parallel lines engraved over them. One Yard (36 ins.) is taken as the di.tance between the central lines on the two golden plugs.

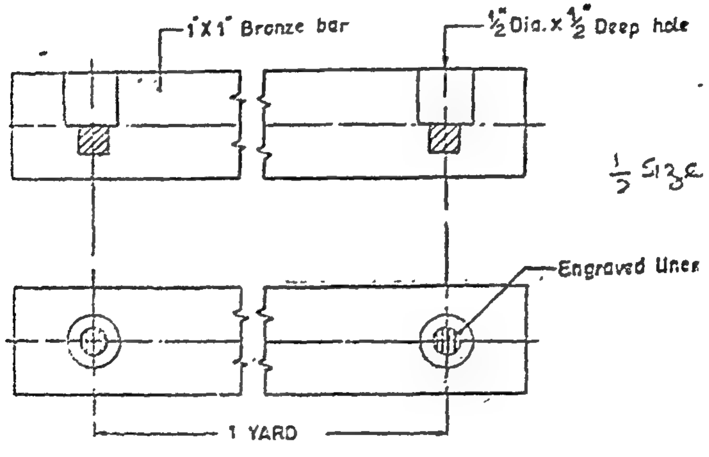


Fig 18·2 Imperial Standard Yard

18.03. INTERNATIONAL WAVE LENGTH STANDARD :

The major draw back with the metallic standards such as the Metre or the Yard has been that their lengths have been found to change over a period of time. In order to overcome such a difficulty wavelength of red radiation of cadmium has been internationally accepted as the standard of measurent. The advantage of such a standard of measurement being that it is more reliable and could be adopted anywhere without the risk of being in error. The wave length of the red radiation from Cadmium is 6438.4696°. Angstrom Unis (1 Angstrom Unit$=10^{-10}$ metre) under the standard conditions

of 20°C temperature, 760 mm atmospheric pressure and 10 mm of vapour pressure.

18.04. INTERCOMPARISONS :

One metre equals 39·370147 in. The American Yard standard is slightly different from the above. One metre in America is taken as 39·370000 American inches. Recent agreement between the British and the American anthorities have fixed the Conversion as 1 in. to 25·4 mm exactly.

18.05. STANDARD SCALES :

Standard Scales Calibrated directly from the Standard Metre are widely used as Substandards by organizations like the National Physical Laboratory and other important engineering organisations. The important point to note about these substandards is their method of support when measurements are being made on them. A bar standard simply resting over two supports would sag and hence the length between the lines engraved on it would change. Geogre Airy showed that the error introduced due to sagging is minimum when the bar is supported over two points $0·577\ l$ apart where l is the length of the bar. These points are known as Airy points and are usually marked on the standard bars.

18.06. LINE AND END STANDARDS :

Imperial Standard Yard and the International Standard Metre are the line standards where the basis of length measurment is taken as the distance between two lines. This form of measurement is not very convenient to use.

End Standards are the standards derived from the line standards. In this case the measurement is done by means of standard bars, slip gauges etc. The distance between the end faces of the bar or the slip gauges directly determines the length of the standard. The end faces are hardened, lapped flat and parallel to a very high degree of accuracy. End standards are convenient to use in tool rooms, workshops, and inspection departments.

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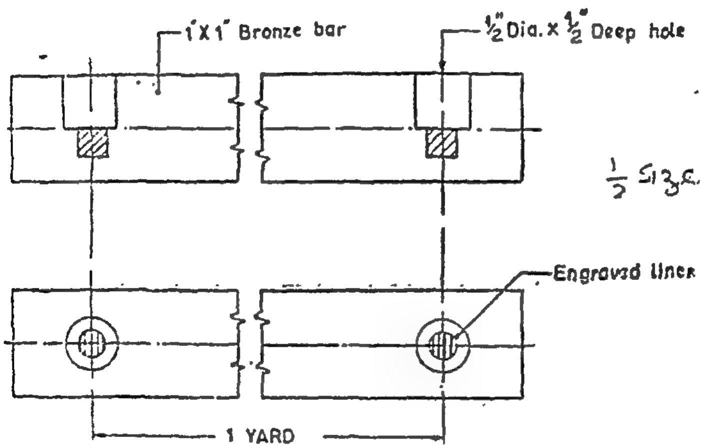

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QUIZ

1. Discuss the advantages of wave length standard over others. Why this form of standard is becoming more common.
2. State the basic difference between line and end standards. How can you calibrate an end standard from the line standard.
3. Name the type of standard (end or line) for the following measurements.

   (*a*) Micrometer (*b*) Scale (*c*) Slip gauge and (*d*) Vernier height gauge.

CHAPTER XIX

LINEAR AND ANGULAR MEASUREMENTS

LINEAR AND AEGULAR MEASUREMENTS

With measurement, using a scale, it is not possible to read scale divisons finer than 0·25 mm. Error is also introduced due to parallax during reading of the scales. In order to overcome these difficulties a number of instruments are available which can measure linear dimensions upto a high degree of accuracy. In broad sense these instruments can be classified into two groups—(*i*) Direct reading instruments and (*ii*) Comparators

Direct reading instruments yield the absolute dimensions of the component being checked whereas a comparator just compares the dimensions of the component against some known standard. The comparator will thus give informations about the deviation of the size from the known standard. The range of measurement of the comparators is very small and hence they cannot used for direct measurement purpose (A full description of the comparators is given in Chapter 20.)

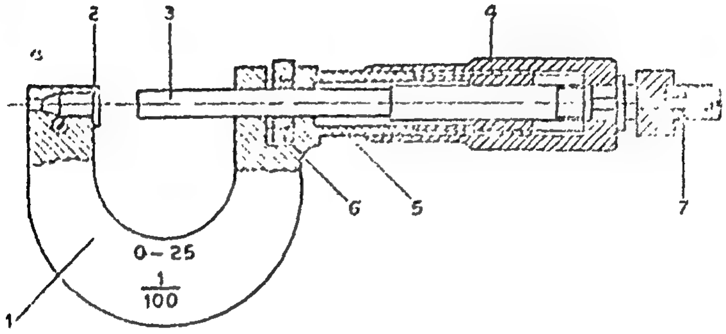
19.1. Direct reading Instruments

Some of the common direct reading instruments for linear measurement are micrometers, vernier caliper, vernier height gauge, slip gauge, measuring machine etc. Micrometers are used for the measurement of out side dimensions *e g.*, diameter of the shaft or for the measurement of inside dimension e.g., diameter of cylinder bore etc. Fig 19·1 and 19·2 show the constructional details of the outside and inside micrometers respectively.

19·1. Differential Screw Micrometer

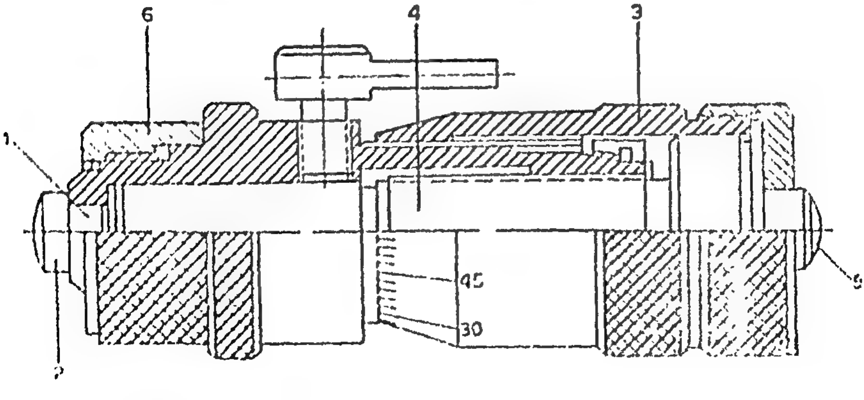
As the name implies, this type of micrometer uses differential screw principle and hence is more accurate than ordinary micremeter. Fig. 19.3 shows a sectioned view of this type of micrometer. A and

B are right hand screw threads cut on the same spindle but have different pitches. By operating the thimble "T" rotation of the screws A, B could be achieved. The periphery of T is graduated into 100 equal parts. Sleeve "S" engages with the screw "A" Via a nut "N" Spindle "D" carries another nut "E" which engage with the screw "B".



1. Body
2. Fixed anvil
3. Spindle
4. Thimble
5. Nut
6. Lock nut
7. Racket Mechinsm

Fig 19.1 Outside Micrometer.



1. Sleeve
2. Anvil
3. Thimble
4. Screw
5. Measuring Tip
6. Thread protection nut

Fig 19.2 Inside Micrometer.

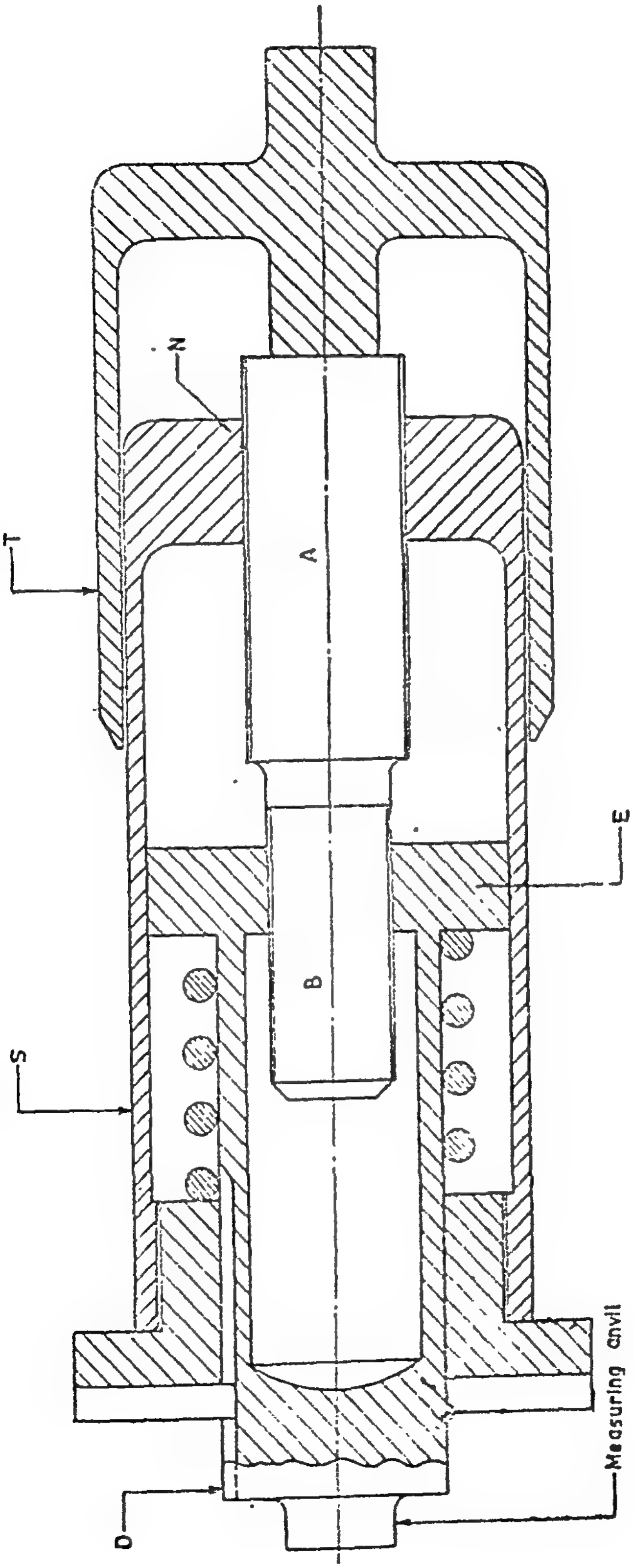


Fig. 19.3 Differential Screw Micro metre

In case of metric-micrometer the usual pitch employed for the screws A and B are 0·5 and 0·4 mm respectively. Therefore for one revolution of the thimble the measuring anvil will advance by an amount equal to (0 5—0·4)=0.1 mm. Since the thimble periphery is grad ated in 100 equal parts hence each division on the thumble wou mean $0{\cdot}1\times\frac{1}{100}=0{\cdot}001$ mm of the anvil movement. The read-in accuracy of this type of micrometer is 10 times better an ordinary micrometer.

19·1.2 Bench micrometer :—The accuracy of measurement with ordinary micrometer depends upon the correct degree of "feel". Bench micrometers overcome this difficulty by ensuring that the measurements are carried out only at a fixed pressure.

The micrometer consists of U-shaped frame of high rigidity. At the right precision micrometer thimble can read directly upto 0.001 mm. On the left is a fiducial indicator capable of 25 mm adjustment. The correct measurement is obtained when the indicator pomter concides with a fixed mark. The pressure of measurement in this case varies between 250 to 275 gms.

19.3. Verneir Calipers

verneir calipers are employed for both internal and external measurements. They are available in sizes ranging from 150 mm to 2000 mm with measuring accuracies upto 0.02 mm.

Verneir calipers (Fig 19.4) consist of two jaws one of them is fixed whist the other with the verneir slides on a beam scale. When the two jaws of the caliper are closed the zero of the vernier concides with the zero of the scale. For precise setting of the movable jaw a screw is provided for fine adjustment. The accuracy of measurement with this instrument will depend upon the degree of "feel" and the straightness of the beam scale.

19.1.4. VERNIER HEIGHT GAUGE

The principle of working of this instrument is similar to the vernier calipers except that it has to be used in conjunciton with

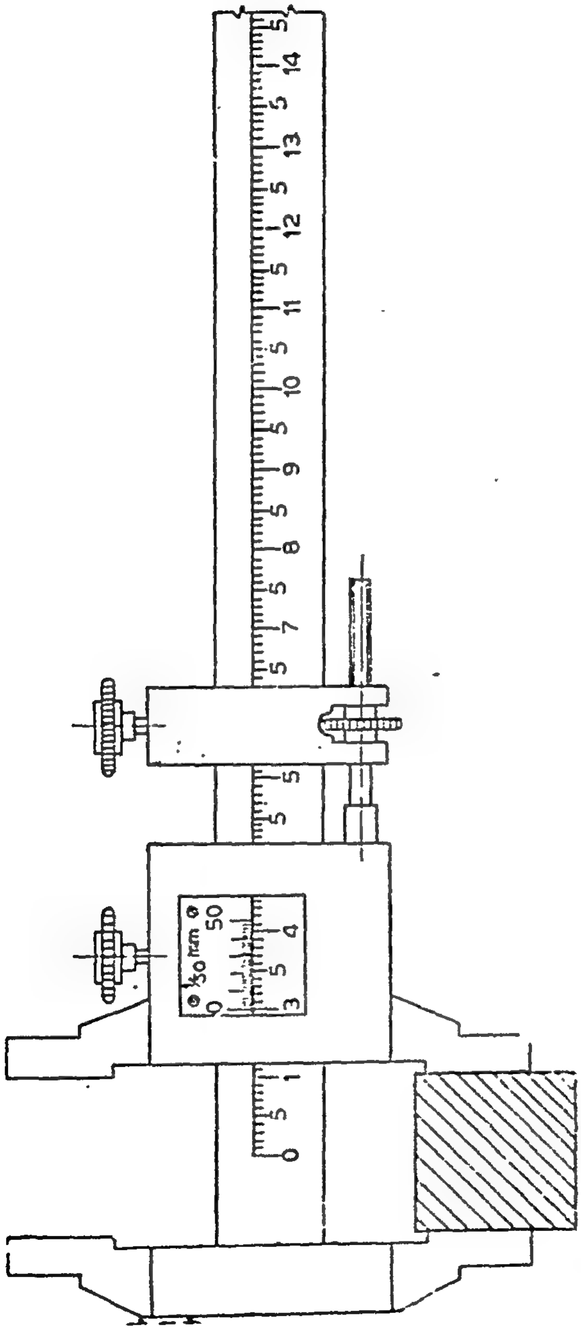


Fig. 19.4 Vernier Calipers

a surface plate. The instrument is used for checking the heights, locating the centre of holes, scribing lines etc. The accuracy of measurement in this case is same as in-case of Vernier Calipers.

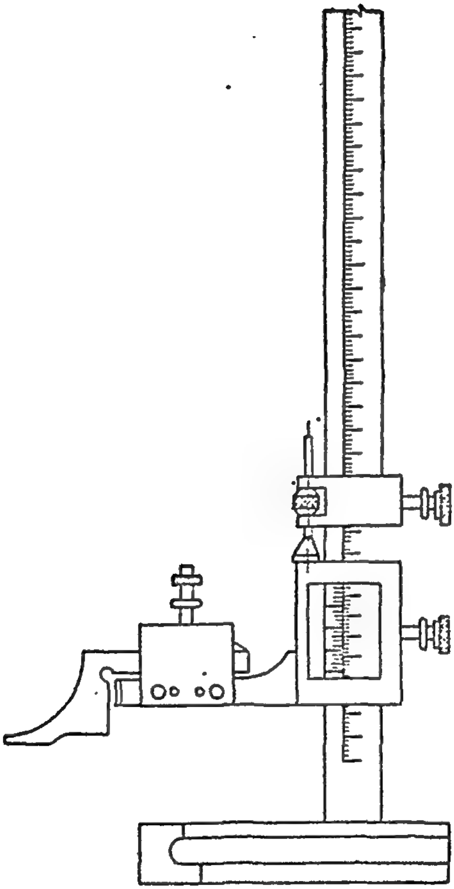


Fig 19·5 Vernier height gauge

19.5. SLIP GANGES

Slip gauges are accurate means of measurement, and are often used for setting up of comparators, and for checking the accuracy of limit gauges. Slip gauges were first designed by Johanson and hence they are sometimes known as Johansson gauge blocks.

Slip gauges are supplied as set a comprising of rectangular steel blocks of different dimensions with opposite faces lapped flat and parallel to a high degree of accuracy. The distance between two opposite faces determines the size of the gauge. A standard metric set of slip gauge will comprise of 103 pieces made up of as follows :

(*a*) 49 pieces ranging from 1.01 mm to 1.49 mm in steps of 0.1 mm.

(*b*) Forty nine pieces with a range of 0·5 to 24·5 mm in steps of 0·50 mm.

(*c*) Four pieces of 25, 50, 75 and 100 mm each.

(*d*) One piece of 1·005 mm.

Apart from these two extra gauges of 2·5 mm each are supplied as protective slips.

Smaller size metric sets are also available with 76, 56, 48 and 31 pieces. The English (inch) slip gauge sets are available with 81, 49, 41, 35 or 28 slips.

During use appropriate number of gauge blocks are wrung together to form the required dimension. Extreme care in handling of the gauge blocks is required. The cleanliness of the surface of the slips, and standard temperature of 20°C during measurement are essential for accurate and reliable inspection. A number of slip gauge holders are sold by the manufacturers of the slip gauges to enable efficient handling. Gauges are available in different grades of accuracy. The common grades being reference, inspection and workshop. The accuracy of the reference grade slip gauge is maximum

Table I

Grade	limit of accuracy blow 2·5·mm size	Limit of accuracy for sizes greater than 2·5 mm.
Reference	5×10^{-6} mm	2×10^{-6} mm/mm.
Inspection	$17 \cdot 5 \times 10^{-6}$mm	5×10^{-6}mm/mm.
Workshop	25×10^{-6}mm	10×10^{-6} mm/mm.

Such gauges are used only for reference calibration purpose. The limits of accuracy guaranteed for various class of gauges is shown in table I. The slip gauges find wide applications in setting up of comparators and other instruments which is described later on.

19.2. MEASUREMENT OF ANGLES

Precise measurement of angles often calls for more skill and ingenuity than linear measurements. In this section some of the important instruments for angular measurement, their use and limitations are discussed.

19.2.1. BEVEL PROTRACTOR

Bevel protractors are often used for the measurement of angle of tapers, bushings and similar machine parts. An ordinary bevel protractor can read accurately upto 2.5 min. The more sophisticated type namely optical bevel protractors can read upto nearest 2 min. An ordinary bevel protractors is shown in fig. 19.6.

19.2.2. SINE BAR

Measurement of angles using bevel protractors is direct whereas sine bars make indirect masurements. Sine-bars are frequently used for setting off angles from a horizontal plane. The accuracy attainable with this instrument is quite high and the errors in angular measurement are less than 2 sec. for angles upto 45°.

A simple sine bar consists of an accurately lapped steel bar (fig. 19.7) with ends recessed to receive two parallel rollers of exactly identical dimensions. The axes of these rollers are parallel to within 0 0015 mm. The centre distance between the rollers is fixed and this distance decides the size of the sine bar. Sine bars are available with centre distance of either 5 or 10 ins. Metric standards sine bars are also available in two sizes namely 100 and 250 mm.

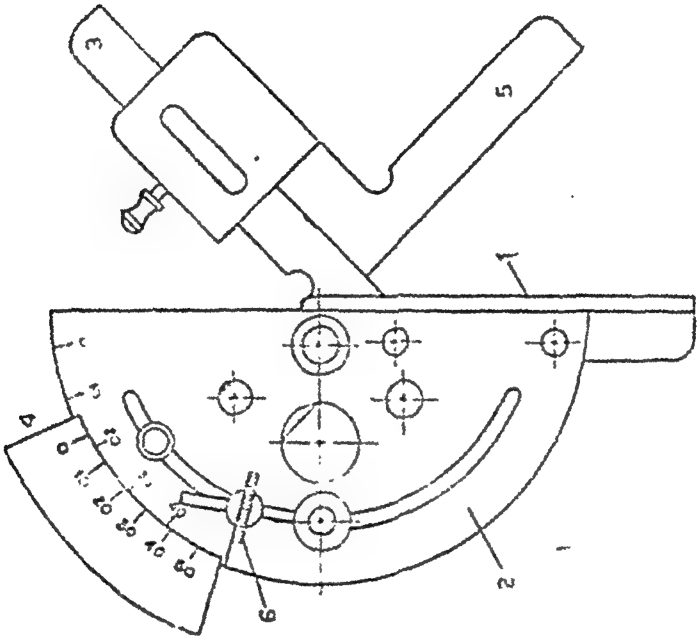


Fig. 19.6

A sine bar has to be used in conjunction with a surface plate and slip gauges.

19.2.3. SETTING UP OF SINE BAR

Alternative methods for setting up of sine bar for any particular job can be employed. The set up to be used will depend upon the nature of the work.

Fig. 19.7 shows a set-up whereby the taper plug gauge angle θ could be measured. The plug gauge "ABCD" is placed on a surface-plate with the sine bar over it as shown. The right side of the sine bar roller is resting on the surface plate whereas under the other

roller a pile of slip-gauge is placed such that the bottom face of the sine bar becomes parallel to the face AB of the plug gauge. The parallelity can be checked either visually or by using a feeler gauge. If "h" mm be the height of the slip-gauge pile required, then the taper angle "θ" is given by $\sin\ \theta = h/L$, where L is the centre distance between the rollers in mm.

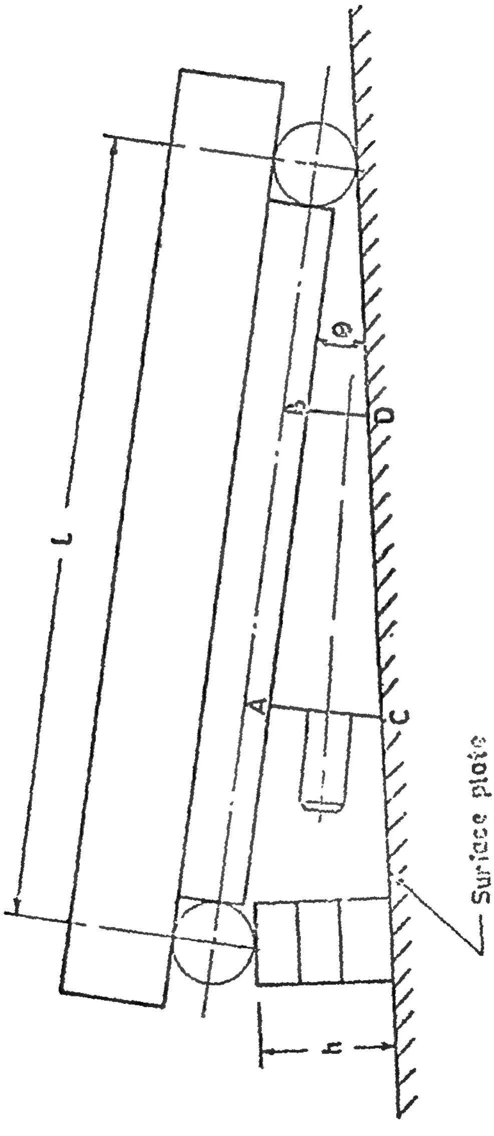


Fig. 19.7

19.2.4. SPIRIT LEVEL

Spirit levels enable the position of a surface to be determined with respect to horizontal. They can, however, be used for the measurement of small angles only.

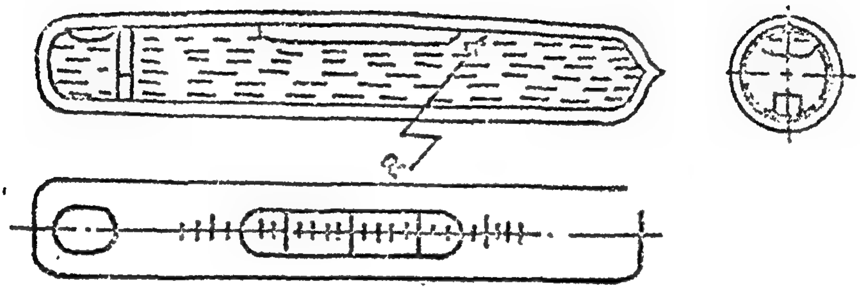


Fig. 19.8

The crossection of a spirit level tube is shown in fig. 19.8. The inside surface of the glass tube is convex and is ground to a large radius of curvature "R". The upper surface of the tube carries a linear scale graduation. The glass tube is carried in a metallic body with a flat base.

If the level is placed over a surface inclined at an angle "ϕ" to the horizontal, the bubble of the spirit level gets disturbed from its highest position. The amount of bubble movement (x) would then be given by

$$x = \frac{R\phi}{206,265} \text{ (mm)} \qquad \ldots(1)$$

where ϕ is measured in seconds.

R=radius of curvature of the bubble tube, mm.

by measuring "x" under the given conditions ϕ can be calculated using equation (1).

The accuracy of spirit levels is likely to be affected due to temperating variations and hence necessary corrections to this effect must be applied if necessary.

19.2.5 AUTOCOLLIMATOR

Autocollimators measure small angular displacements from which it is possible to determine, straightness, flatness, alignment etc.

The principle of working of an auto-collimator is based upon the fact that when a ray of light incident on a surface is deflected by an angle "α" the reflected ray will rotate by an angle 2α.

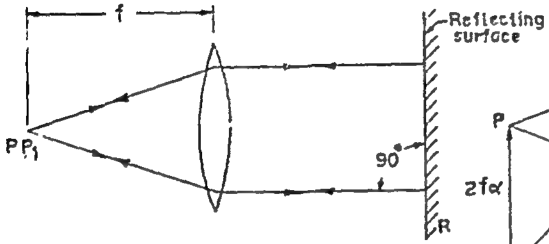


Fig. 19.9 (*a*)

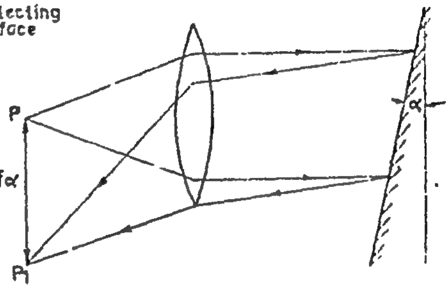


Fig. 19.9 (*b*)

Fig. 19.9 (*a*) shows a light source P situated at the focus of the lense If the reflecting surface, exactly at right angles to the path of the light, is placed at R then the image P^1 of P will coincide with P itself. However, if the reflecting surface is inclined at angle "α" (fig. 19.9 *b*) the image P^1 of P will now be displaced by an amount $2f\alpha$ where f is the focal length of the lens used.

Thus by measuring the linear distance PP^1 the inclination of the reflecting surface (α) can be determined. In actual working the work surface whose inclination is to be obtained forms the reflecting surface and the displacement PP^1 is measured by a precision microscope which is calibrated directly to give the values of "α". Auto-collimators are quite accurate and can read upto 0·1 second. However their range of measurement is small hence they as more useful as a comparator rather than when used for absolute measurement. Another novel feature of this type of instrument is that their working distance can be quite large. Sometimes it may be as large as 30 meters.

For efficient working of the auto collimators the work surface must be highly polished and should be optically flat. Sometimes slip-gauges are mounted on the surface to be measured, this helps in obtaining good reflection from the surface. Other types of reflectors available as standard equipment are optical square, optical flats coated with rhodium

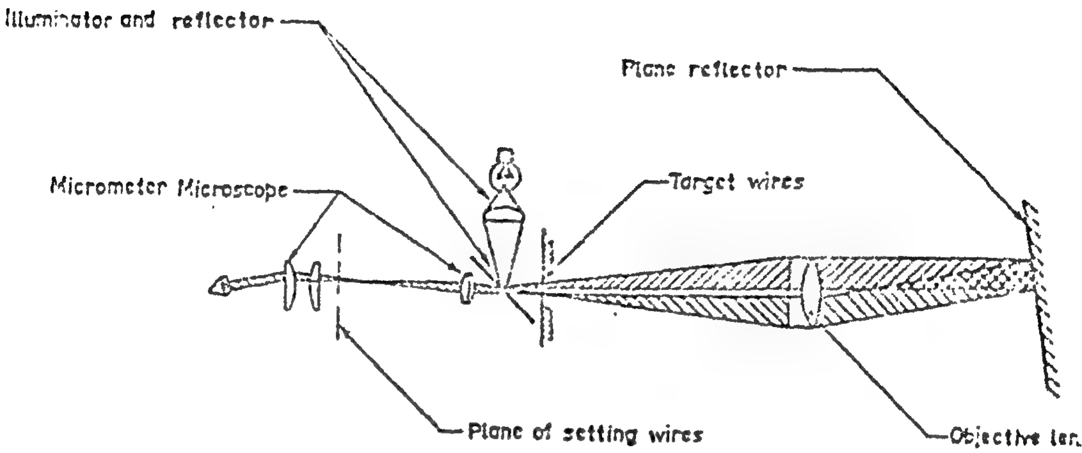


Fig. 19.10. Optical System of an auto-collimator

The optical system of an auto-collimator is shown in fig. 19.10. The target wires are illuminated by the electric bulb and act as a source of light. The image of the illuminated wire after being reflected from the surface being measured is formed in the same plane as the wire itself. The eyepiece system containing the micrometer microscope would measure the difference in the position of the reflected image of the wire and the wire itself.

SETTING UP AN AUTOCOLLIMATOR

Autocollimator works on the same principle as a comparator. It compares the angle to be measured against a known standard. During linear measurements the standard is set with the help of slip gauges. During angular measurement with autocollimator the datum is set with the help of angle blocks. These blocks are rectangular in shape with three square faces accurately ground and lapped.

The fourth face of the block is ground at a known angle (fig. 19.11). The blocks are available as a set containing 12 pieces having following angles.

1°, 3°, 9°, 27°, 41°, 1 min, 3 min, 9 min, 27 min, 0.1 min,

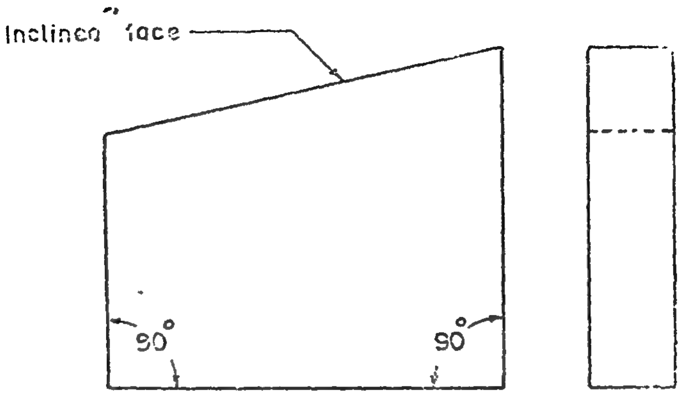


Fig. 19.11

0.3 min and 0.5 min. By combining these blocks, angles upto 81° 40.9′ can be set. Angles greater than this can also be formed with the help of an optical square. The setting of any angle with the angle blocks require same precautions as are usually applied to the use of slip gauges. Figs. 19.12 and 19.13 show the setting of angle blocks for two different angles.

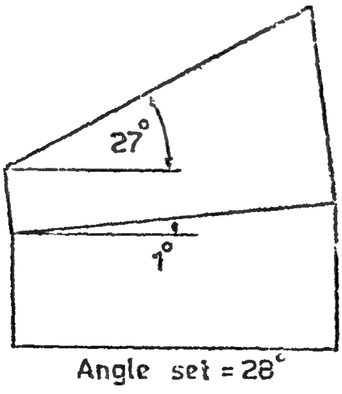


Fig. 19.12

Suppose it is required to check the angle θ of the taper plug gauge (fig. 19.14). Firstly, with the help of angle blocks the standard value of the angle θ is set. The auto-collimator axis is now set square to the angle θ over the angle blocks. The auto-collimator

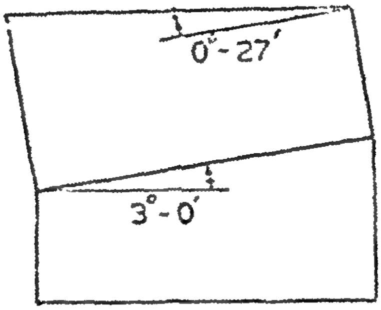


Fig. 19.13

eyepiece is next operated so that the target wire and its reflected image may coincide. Next the plug gauge is brought under the auto collimator. If there is a difference between the plug gauge angle and the angle set by the block the target wire image will no longer coincide with the target wire. The amount of eyepiece

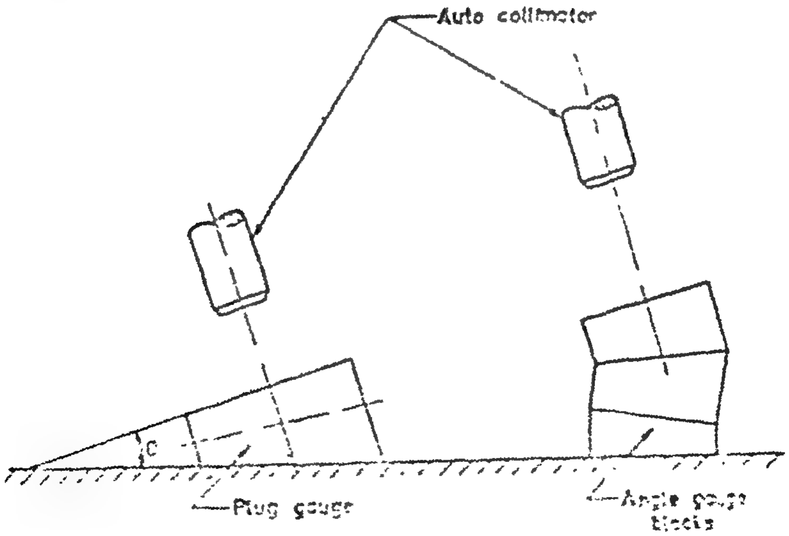


Fig. 19.14

movement required to bring the target wire and its image back to the point of concidence will give the difference between the datum angle set by the angle blocks and the plug gauge angle.

Auto collimators have a number of applications in precision measurement. They can be used for alignment checking flatness and straightness checking etc.

19.2.6. MEASUREMENT OF TAPERS

A number of special methods are available for the measurement of tapers. These methods are applicable to both inside and outside taper measurements. Few of the methods described here make use of the simple laws of geometry in order to find the taper angles.

Measurement of Internal Tapers

Suppose, it is required to find the included angle of a tapered ring gauge of small diameters.

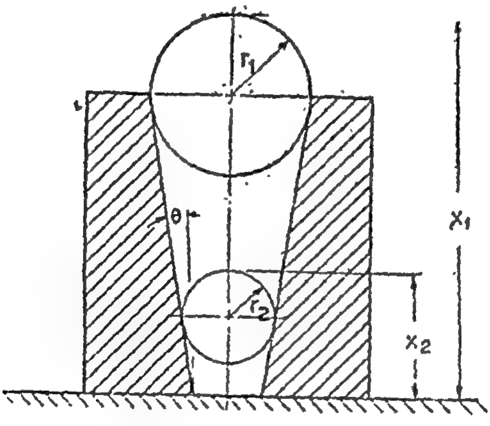


Fig. 19.15

In order to measure the taper angle the ring gauge is placed on a surface plate and two balls of radii r_1 and r_2 respectively are inserted into the ring gauge as shown in fig. 19.15. The radii r_1 and r_2 of the balls have to be such that two balls touch the walls of the gauge around its circumference. After inserting the balls the distance x_1 and x_2 are measured accurately using an accurate instrument. The taper angle can now be calculated from the geometric relation

$$\tan\theta = \frac{r_1 - r_2}{(x_1 - r_1) - (x_2 - r_2)}$$

If the taper ring gauge diameters are large and its length is small (fig. 19.16) it may not be possible to obtain balls of convenient diameters so as to enable the measurements to be taken up by the method described above. In such cases the type of arrangement as shown in fig. 19.16 would be more useful. In this case four balls of equal radii are used. Balls 1 and 2 are placed over the datum surface and just touching the walls of the ring gauge. Balls 3 and 4 are each placed over a pile of slip gauges of height "S" and just touching the periphery of the ring gauge. Measurements x_1 and x_2 are obtained by the use of internal micrometers. The taper angle θ can now be calculated from the relationship.

$$\text{Tan}\ \theta = \frac{x_2 - x_1}{2S}$$

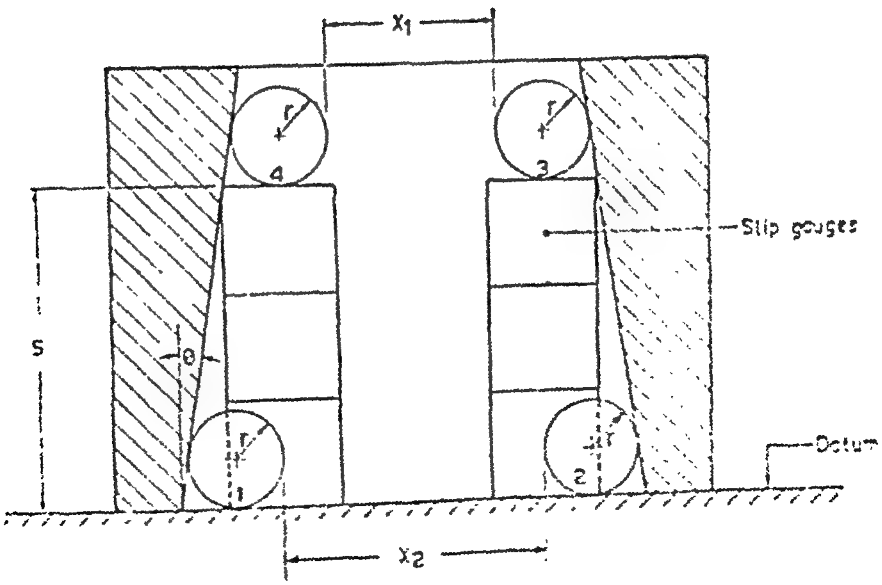


Fig. 19.16

External Tapers

Same principle as described above can also be used for the measurement of external tapers. Fig. 19.17 shows a set up for the measurement of taper angle of a plug gauge.

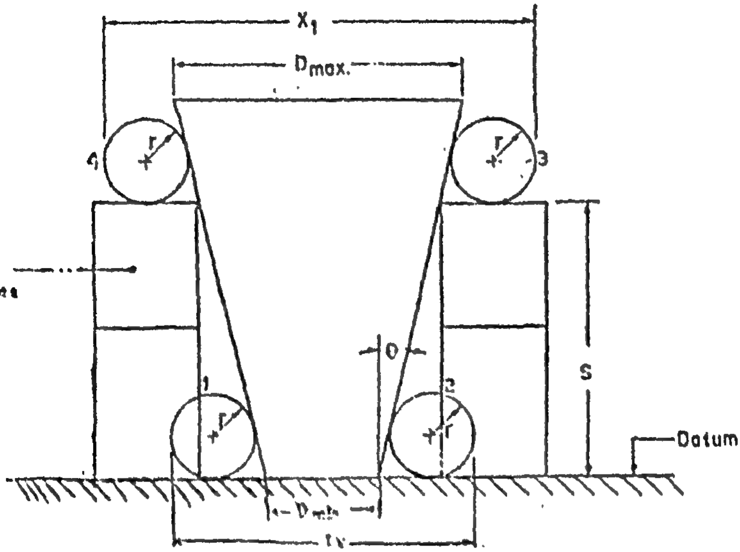


Fig. 19.17

The method employs 4 rollers of equal radii "r" placed along the plug gauge as shown and measurements X_1 and X_2 have to be obtained by the use of a micrometer. The taper angle "θ" can be calculated by the relationship

$$\tan \theta = \frac{X_1 - X_2}{2S}.$$

The above set up would also give the diameters D_{max} and D_{min} of the plug gauge. Referring to Fig. 19.17 it can be derived that

$$D_{max} = X_1 - 2\{r(\sec \theta + 1) - (H\text{-}S\text{-}r) \operatorname{Tan} \theta\}$$

$$D_{min} = X2 - 2r\{\sec \theta + \operatorname{Tan} \theta + 1\}$$

Where H is the height of the plug gauge.

19.2.7. DOVE TAIL ANGLE

The dovetail angle could also be measured by the method described above fig. 19.18 shows a simple set up to be used for the measurement of the dovetail angle "θ".

The dovetail is placed over a datum surface such as a surface plate. Two rollers of equal radii "r" are placed across the dovetail sides as shown (Fig. 19.18). The distance "X" over the rollers is measured by a micrometer. The dovetail angle θ can be calculated from the relationship.

$$X = M + 2r\left(1 + \cot\frac{90° - \theta}{2}\right)$$

$$\text{and } C = r\cot\left(\frac{90 - \theta}{2}\right)$$

One of the objections to the use of balls or rollers for precision measurement is that the balls are liable to get deformed due to the measuring pressure and hence the accuracy of calculation is to be affected.

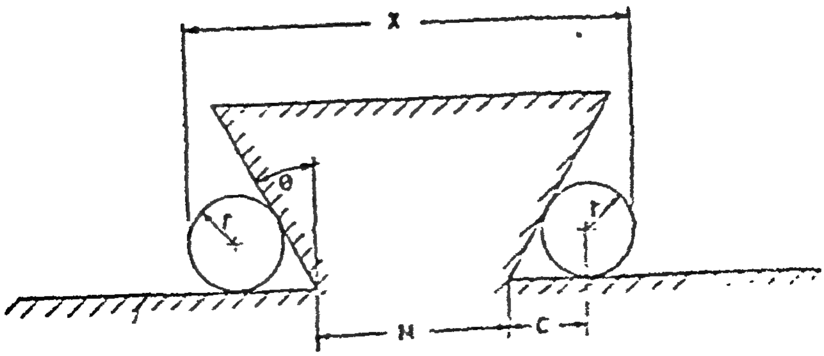


Fig. 19.18

QUIZ

1. Describe the working of a vernier caliper. Indicate by means of suitable sketches how this instrument could be used for the measurement of (*a*) shaft diameter (*b*) internal diameter of a bush.

2. Explain the working of a differential screw micrometer. How larger magnification as compared to simple micrometer is achieved in this case ?

3. Exolain what is meant by the grade of a slip gauge ? What grade of slip gauge will you employ for checking the accuracy of a plug gauge ? Give reasons for your choice.

4. Explain the principle of a Sine bar. With a neat sketch, explain how this instrument could be employed for checking the angle between two non-parallel sides of a trapizoidal steel block.

5. Explain, how an autocollimator can be used (*a*) to check the alignment between two bearings of a machine tool. (*b*) perpendicularity between two surfaces.

6. What are common sources of error in angular measurement by balls ? Explain how will you check the diameter of a ring gauge using balls. Give a list of equipment needed.

CHAPTER XX

COMPARATORS

Comparators are employed to find out how much the dimensions of the given component differ from that of a known datum. The indicated difference in the dimension is usually small and hence suitable magnification device should be employed to obtain the desired accuracy of measurements. Use of comparators in precision measurement is fairly common owing to the simplicity in measurement which also eliminates the need for skilled workers in inspection jobs.

The comparators are classified according to the type of magnification device they employ, the common types are

(1) Mechanical Comparator.

(2) Electrical Comparator.

(3) Optical Comparator.

and (4) Pneumatic Comparator.

20.1. MECHANICAL COMPARATOR

A mechanical comparator employs mechanical means for magnifying the small movement of the measuring styles brought about due to the difference between the standard and the actual dimension being checked. The mechanical comparator has the advantage of being self contained with no requirements of power or any other form of supply. They are of robust design and of low cost. On the other hand the moving parts of the mechanical comparator are liable to wear and hence the working accuracy over long periods is affected.

Mechanical comparators of different make each one having its own characteristic design are available. Some of the notable makes of Mechanical Comparators are—Sigma, Venwick, John Bull, Mercer, Mikrokator etc. The method for magnifying the small stylus movement in all the mechanical comparators is by means

of levers, gear-trains or a combination of these. The order of magnification possible with these type of instruments is limited to 1000. The simplest form of mechanical comparator is a dial gauge.

20.1.1. DIAL GAUGE

Fig. 20.1 shows a sectioned view of the dial gauge. The small movement of the stylus "S" in this case is magnified by a high velocity-ratio gear train resulting into appreciable movement of the pointer. Dial gauges are usually available having dial graduations of 0.01 mm. or 0.001 in. Some of the sensitive type of gauges have graduations of 0.002 mm or 0.0001 in.

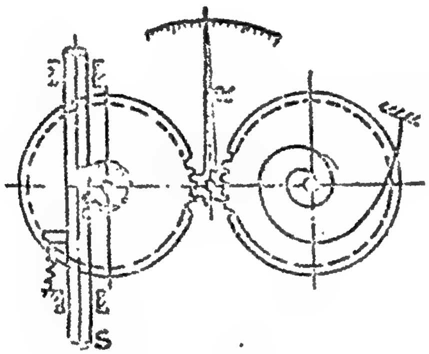


Fig. 0·1

A mechanical comparator differs from the dial-gauge in a number of ways. The range of measurement in case of mechanical comparators is much smaller as compared to dial gauges. On the other hand a mechanical comparator is a self contained unit having its own work supporting table, vertical column, and means for the adjustment of the measuring head height.

20.1.2. PRINCIPLE OF A MECHANICAL COMPARATOR

Fig. 20.2 shows a schematic diagram of a mechanical comparator. The measuring stylus "S" through a knife edge k_1 bears against a beam (B) supported over the two knife edges k_1 and k_2 as shown. The knife edge bearings k_1 and k_2 are jewelled to reduce friction and hence improve the working accuracy. Due

to the movement of the measuring stylus the beam (B) is tilted resulting into deflection of the pointer (P) over the graduated scale (G). The amplification attainable in this case will be determined by the ratio $\frac{L}{a}$.

The contact pressure during the measurement with the comparator is provided by a spring (C). The force exerted by the spring should be between 300—400 gms. The boundries of the

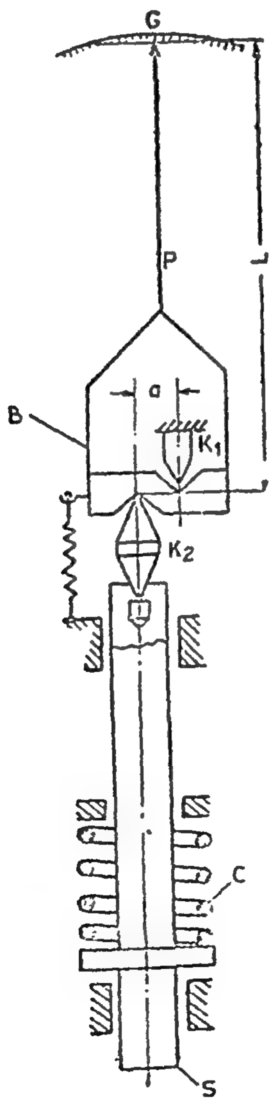


Fig. 20.2

tolerance zone may be indicated on the scale by means of two adjustable tolerance marks.

20.2. ELECTRICAL COMPARATOR

The electrical comparator offers a number of advantages over the mechanical type. They have little or no moving parts and hence can retain their accuracy over long periods. Also sensitivity of these comparators could be adjusted at will to suit the type of measurement being done. In general a higher magnification is possible with these comparators as compared to mechanical type.

An electrical comparators on the other hand is not self contained and needs stabilized power supply for its operation. The accuracy of working of these comparators is likely to be affected by temperature and humidity.

20.2.1. WORKING PRINCIPLE OF ELECTRICAL COMPARATOR

An electrical comparator consists of four basic units

(*i*) Measuring probe.

(*ii*) Amplifier and indicating unit.

(*iii*) Power unit.

(*iv*) Base and stand unit.

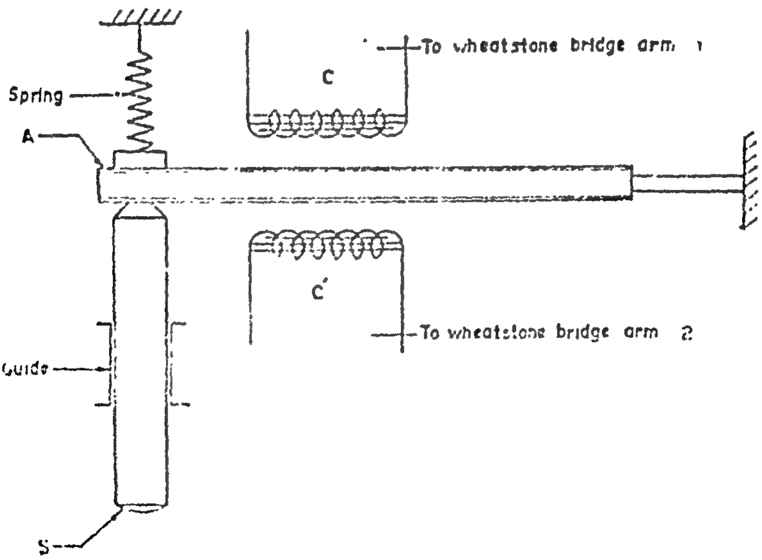


Fig. 20.3 (*a*)

A schematic diagram of the measuring probe is shown in Fig. 20.3 (*a*). It comprises of a stylus "S" having hardened spherical end. An iron armature A held by a leaf spring at one end and resting against the stylus (S) at the other is placed in between two coils C and C′. The coils C and C′ form two arms of an A.C. Wheatstone bridge (Fig. 20.3 (*b*). The air gap between the armature A and the coils C and C′ could be varied to change in the sensitivity of measurement.

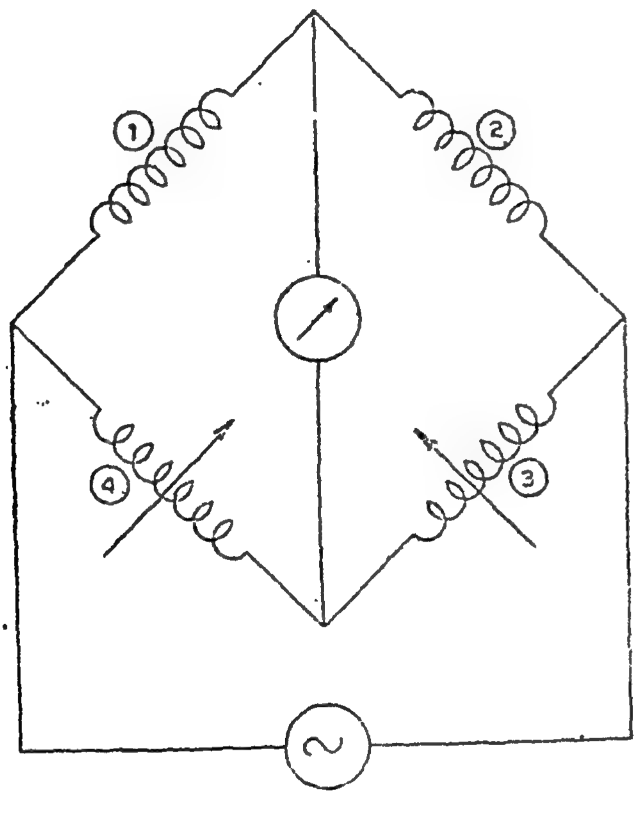


Fig. 20.3 (*b*)

When the armature A is centrally located between the coils C and C′. The inductance of both the coils is equal and the bridge is balanced. This condition would correspond to the situation when the comparator is set against the datum. When a component is placed under the stylus for the purpose of measurement because of difference between the datum size and the component size at the stylus "S" and hence the armature "A" would either be lifted upwards or lowered down. This would upset the

balance of the Wheatstone bridge, resulting into the flow of unbalanced current within the bridge. The direction of flow of the unbalanced current would indicate whether the component is larger or smaller than the datum. A suitable calibration of the unbalanced current would also indicate the difference between the component size and the datum size.

The amount of unbalanced current is usually too small to measure and hence the current is suitably amplied before being displayed on the measuring dial.

Electrical comparators are available to read upto 0.0001 mm with magnification ranging between 1125—18000. These comparators could also be supplied with indicators which would give out a signal if the component being checked lies above or below the specified limits. The signal from the indicator may either be in the form of a glowing light bulb or a buzzer sound. This system is particularly useful in inspection of large number of similar components.

20.3. OPTICAL COMPARATORS

Optical comparators have a high degree of precision and suffer less wear during usage than the mechanical type. Magnification in case of optical comparators is obtained with the help of light beams which have the advantage of being straight and weightless. The accuracy of measurement of this type of instrument is usually limited to 0.001 mm. Optical comparators have their own built-in illuminating device which tends to heat the instrument. Accuracy of measurement is liable to suffer due to this.

20.3.1 Working principle of an optical comparator.

The optical system of typical comparator is shown in fig. 20·4. It consists of an eye-piece "E", a reticule "R" on which scales are engraved on the side facing the prism "P". Objective lense O, a tilting mirror "M" mounted over knife edge, and the comparator spindle "S". A light source, usually a low-powdered electric-bulb is used to illuminate the scale on the reticule "R".

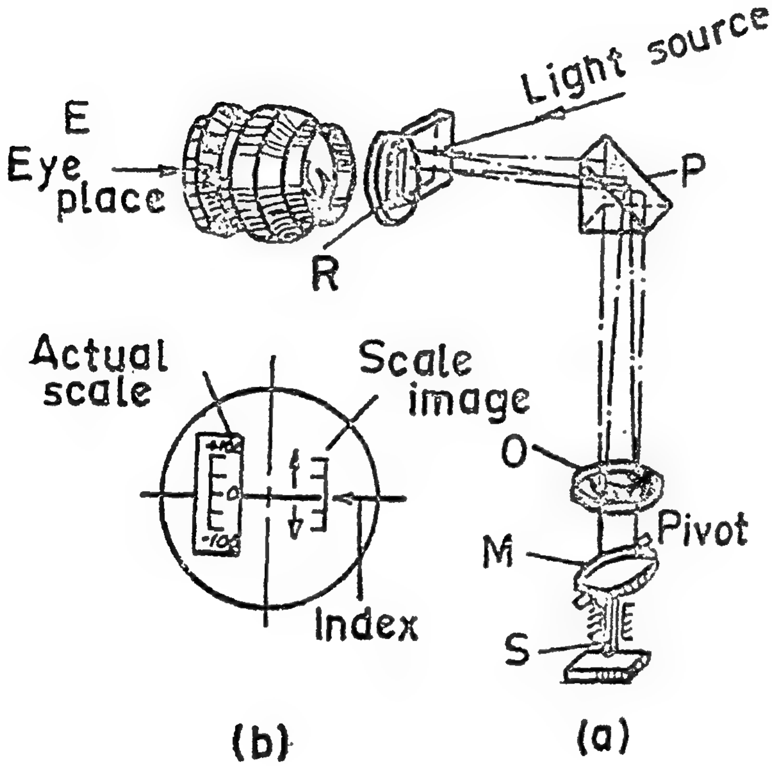


Fig. 20.4

When viewed through the eye-piece the eye observes the image of the scale reflected by the tilting mirror "M". A fixed reference line is provided in the focal-plane of the eye-piece, and the reflected image of the scale is superimposed against the reference mark (Fig. 20 4 b). When a component is inserted under the plunger of the comparator for measurement purpose which has been press against known datum. The movement of the plunger will cause the mirror "M" to rotate about its tilting axis. The position of the scale

image against the reference mark reflected by the tilting mirror "M" will now change. This change can be read directly through the eye-piece "E" which would give the difference between the standard and the actual dimension. A number of different alternative designs of the equipment are available.

20·3.2 Optical flat as a comparator.

An optical flat works on the principle of light interference. It is made of quartz disc with two plane flat faces parallel to each other (Fig. 20·5). A mono-chromatic source of light is usually required for efficient working of an optical flat.

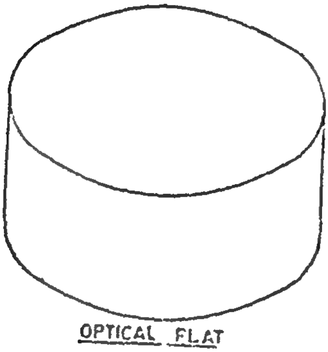


Fig. 20.5

Principle

Fig. 20.6 shows an optical flat resting on the surface to be checked. It is very unlikely that the flat will lie parallel to the surface. In Fig. 20.6 the flat is shown to be tilted slightly an angle with respect to the surfaces. Consider a mono-chromatic ray of

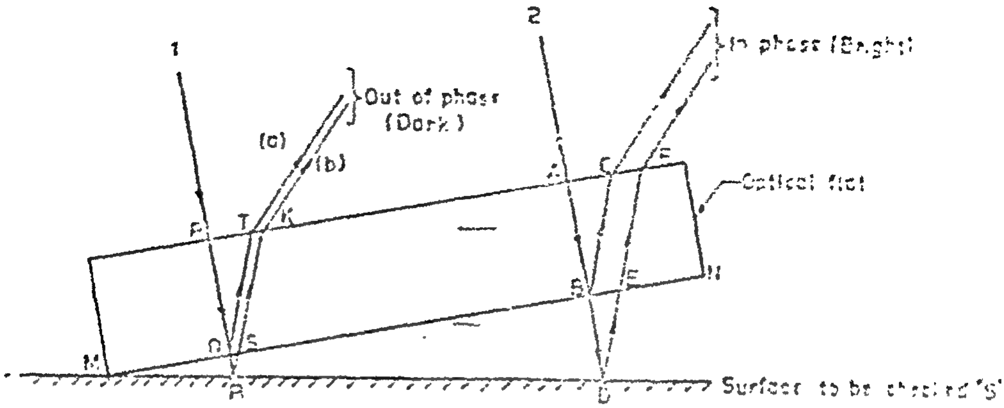


Fig. 20.6

light shown as (1). This ray will enter the optical flat at P and will follow the path PQ. At Q a portion of the ray will be reflected back along the path QT by the inner surface MN of the optical flat. Remainder of this ray is refracted along the palh QR and finally reflected back along the path RSK, by the work surface "S". The two rays (*a*) and (*b*) emerging out at T and K can be viewed with the help of eye. The rays *a* and *b* have traversed different paths the length of the path followed by "*a*" is "PQT" where as the length of the path followed by "*b*" is "PQRSK". The difference in the length traversed by "*b*" and "*a*" is (QR+RS). If the difference in the path length happens to be a multiple of the wavelength of the light, a fringe will be observed by the eye. A dark fringe will occur if the difference happens to be an even number of $\frac{1}{2}$ wavelength (λ) of the light being used. A bright fringe will occur if the path difference is an odd number of $\frac{\lambda}{2}$ wavelength of the light and the two rays *a* and *b* will be in phase. The phase difference between any two successive bright and dark fringes will therefore be $\frac{1}{2}$ the wavelength of the light.

Referring to Fig. 20.6 the path difference between the bright and dark fringes would be

$$(BD+DF)-(QR+RS)=\frac{\lambda}{2}$$

As the difference between BD and DE is very small, it can be said that

$$BD=DF \text{ and } QR=RS$$

hence $$2BD-2QR=\frac{\lambda}{2}$$

or $$BD-QR=\frac{\lambda}{4}$$

half wavelength of red helium light is 9.000333909 mm. therefore difference in the heights of the air gaps BD and QR would be equal to 0.000166954 mm.

20.3.3. Checking the height of a component.

The height of a given component can be checked against a known standard by the use of an optical flat.

The component "C" and the standard gauge block "G" are wrung to a reference sutface, at a known distance "x" apart Fig. 20.7 *a* and *b*. An optical flat is placed over the two as shown. As the height of the reference gauge is slightly different from that of the component being checked the optical flat will be inclined at a small angle thus producing an air wedge.

If N number of dark fringes are observed over the width "L" mm. of the block "G".

x=distance in "mm" (Fig. 20.7)

λ=wavelength of light being used in mm.

Then the difference in the height $h=\frac{\lambda}{2}\frac{xN}{L}$ if $x=50$ mm., L=25 mm., N=5 and $\frac{\lambda}{2}=0.000333909$ mm.

$$h=0.000333909\times\frac{50\times5}{25}$$

$$h=0.000333909 \text{ mm.}$$

By the method just described we can estimate the difference the heights of the standard and work dimensions. However, it is still not known whether the work is higher than the gauge "G" or *vice versa.* To find this the optical flat is pressed lightly with finger over the gauge block 'G'. If the gauge block is higher than

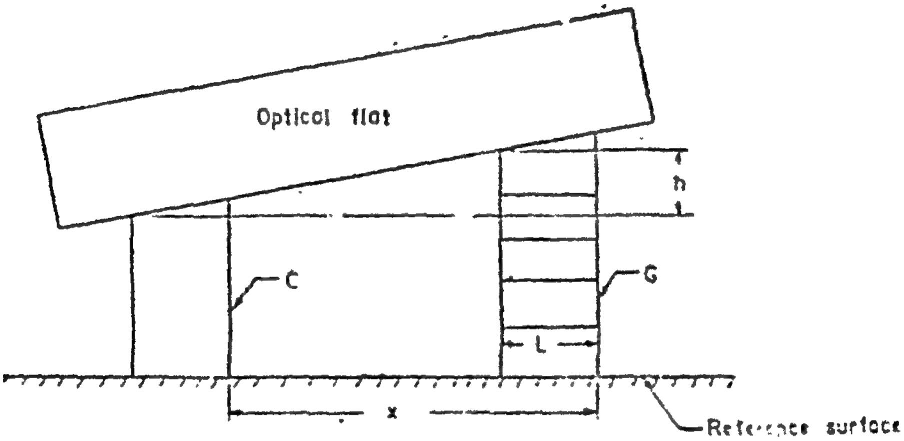


Fig. 20.7 (*a*)

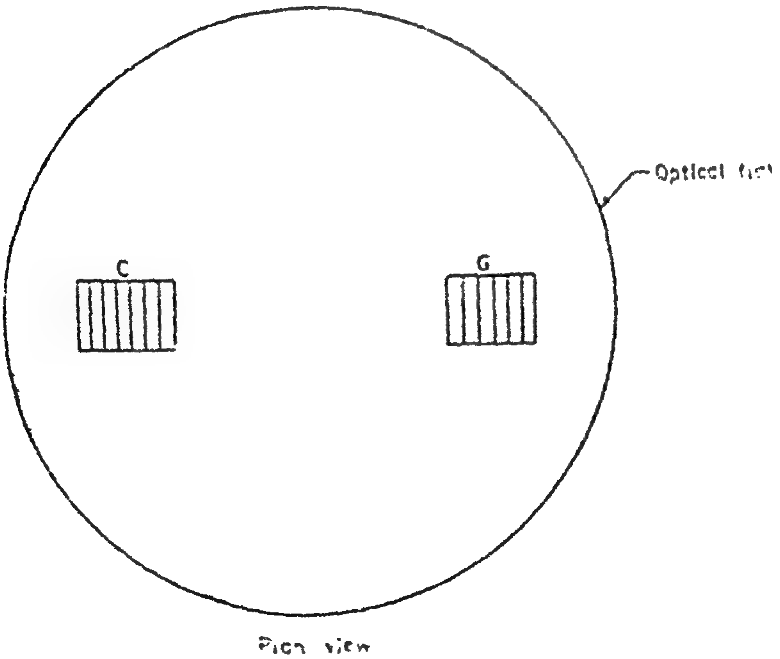


Fig. 20.7(*b*)

the work-piece the air gap between "G" and the optical flat will tend to become parallel and hence the fringes will move farther apart. However, if the component 'C' is higher than the gauge G, application of pressure would result in further increase of the air gap wedge and hence the fringes would come closer.

20.3.4. Checking the flatness.

The optical flat can also be used to check the flatness of surfaces. Fig. 20.8 shows different fringe patterns obtained by using an optical flat.

Fig. 20.8 (*a*) is a spherical surface since the fringes are widely spaced at the centre than at the edges.

Fig. 20.8 (*b*) shows the presence of a ridge ox a valley. The exact nature of the defect can be found out by the application of light finger pressure.

Fig. 20.8 (*c*) shows a perfectly flat surface but the contact in this case is not good.

Fig. 20.8 (*d*) shows an ideally flat surface and in this case no fringes are observed,

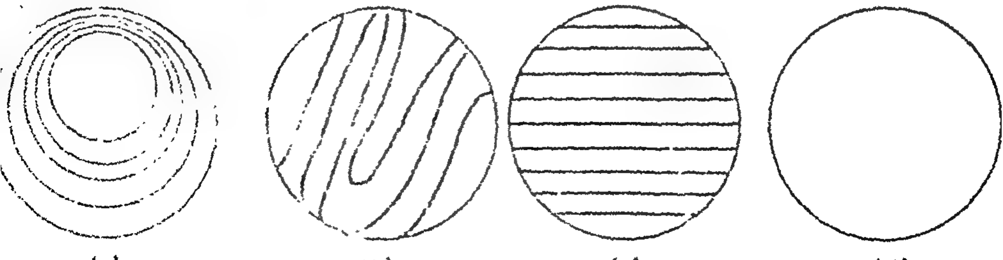
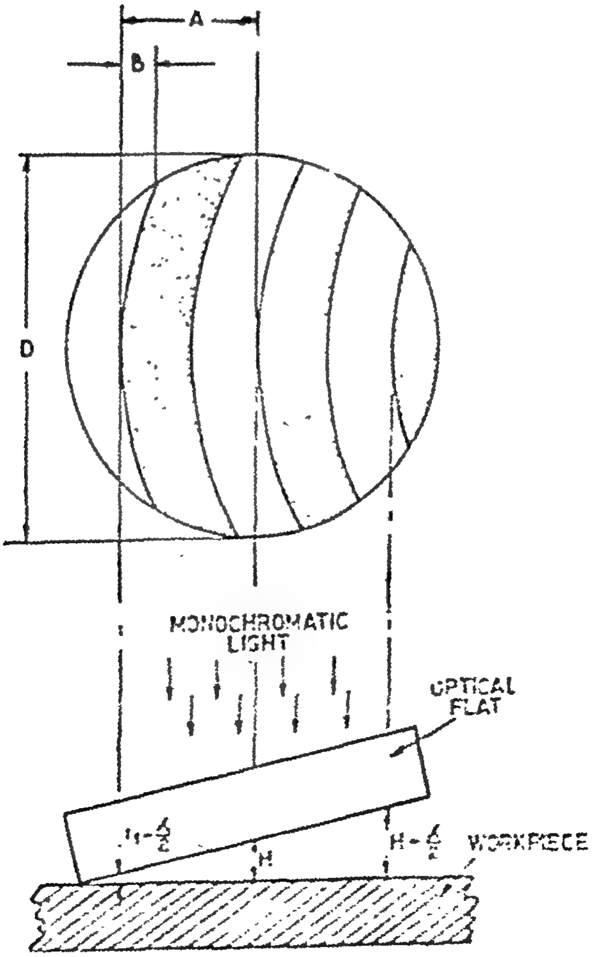

(a) (b) (c) (d)

Fig 20.8

To determine the magnitude by which a surface is concave o
convex the following procedure can be adopted.

Fig. 20.9 shows an optical flat placed on the work surface fo
measurement purpose. As the surface is not flat the type of fring
pattern will be as shown. The amount by which the surface
concave or convex over the diameter D is given by $\frac{B}{A} \cdot \frac{\lambda}{2}$ where
is the wavelength of monochromatic light used during the exper
ment.



20.5. *Pneumatic Comparator.*

During the recent years use of pneumatic comparators has been extensive specially in automatic size control. This form of comparator offers a number of advantages. Such as being cheap, independent of the contact pressure and simple to operate. Besides, this form of comparator is free from mechanical hysterisis and wear. However, the pneumatic comparators are sensitive to temperature and humidity changes. Their accuracy may also be influenced by the surface roughness of the component being checked. The magnification possible with this type of comparator is as high as 10,000.

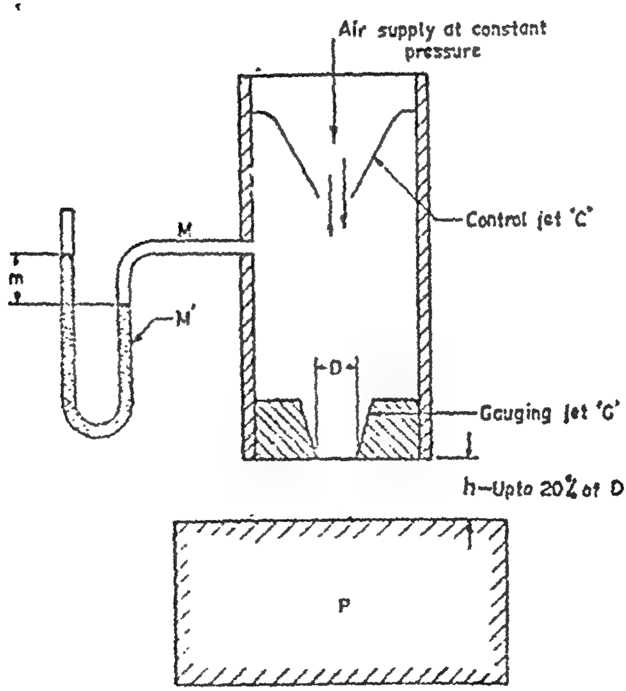


Fig. 20.10

Principle of Working.

The principle of working of a pneumatic comparator can best be understood by referring to fig. 20.10. Air at constant pressure of about 1.5 kg/cm² is supplied to the control jet C. Measured amount of air flows from the control jet C to the gauging jet G. The component whose size is to be measured is shown as P. The amount of air escaping within a given time through the annular gap between the work-piece P and the gauging jet G will depend upon the gap *h*. The amount of gap "*h*', wiil affect the pressure recorded by the manometer M′. If the gap "*h*" is large the pressure recocded by the manometer would be small. On the other hand if the gap *h* is small the manometer M′ will register higher pressure values. The manometer reading is therefore a measure of the gap *h*.

In order to use this instrument as a comparator the gap "*h*" is initially set with the help of a known reference usually a slip gauge. The component whose dimension is to be checked is next placed under the gauging jet "G". The component would usually be be slightly larger or smaller than the reference and hence there will be a variation in the air gap *h* which would result into a change in the manometer reading. The manometer in such gauges is callibrated directly to read linear dimensions.

This form of gauging can be applied to internal and external diameter measurements, thickness measurements. It can also be applied to check the concentricity of annular parts, depth of blind holes etc.

Quiz :

1. Discuss the relative merits and demerits of the following types of comparators :

(*a*) Mechanical (*b*) Optical and (*c*) Electrical.

2. Describe the working principle of an optical flat. How will you check the height of a given rectangular steel block by this method ?

3. Describe the working principle of an (*a*) mechanical and (*b*) pneumatic comparator. Which of the two you would employ for continuous checking of shaft diameter into turning ?

4. Describe the principle of working of an optical comparator. Indicate the sources of error in this case.

CHAPTEk XXI

INSPECTION OF SCREW THREADS AND GEARS

21.1 Elements of screw threads :

The performance of screw threads during their assembly with nut would depend upon a number of parameters such as the condition of the machine tool used for screw cutting, work material tool etc. The inspection of the screw threads would reveal the nature of defects present. Before we actually describe the inspection method let us define some of the common terms used in this connection.

21.1.1. DEFINITIONS.

Pitch.. Pitch of a screw thread is defined as the distance measured parallel to the screw thread axis between the corresponding points on two adjacent threads in the same axial plane. (Fig. 21.1)

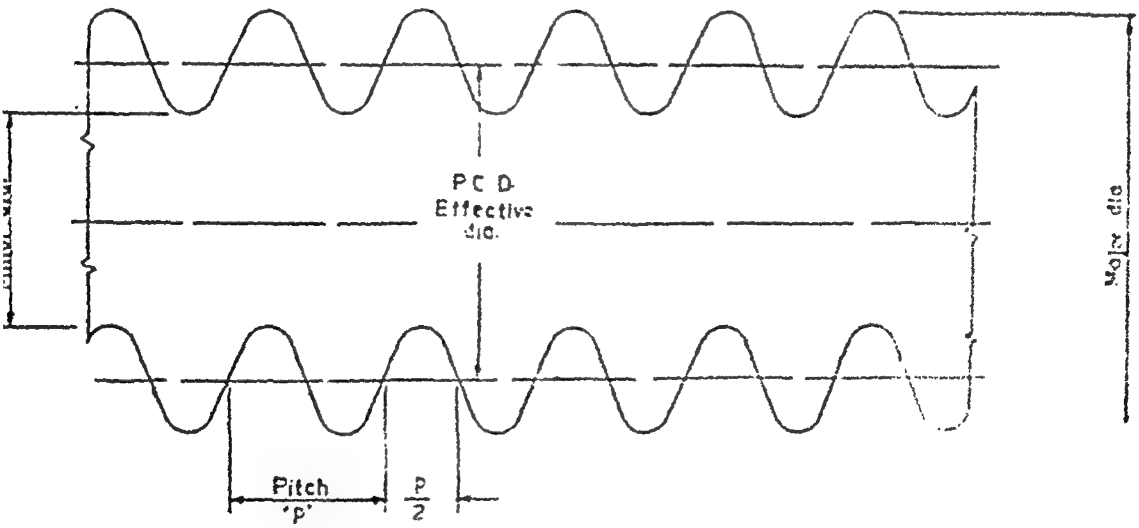


Fig. 21.1. Elements of a screw thread.

Lead. The axial distance advance by the screw in one revolution. For multistart thread

Lead=pitch × No. of starts.

Major diameter. It is the diameter of an imaginary co-axial cylinder which touches the crests of an external thread and the root of an internal thread (Fig. 21.1).

Root or Minor diameter : It is the diameter of an imaginary co-axial cylinder which touches the roots of an external threads or the crests of an internal thread (Fig. 21.1).

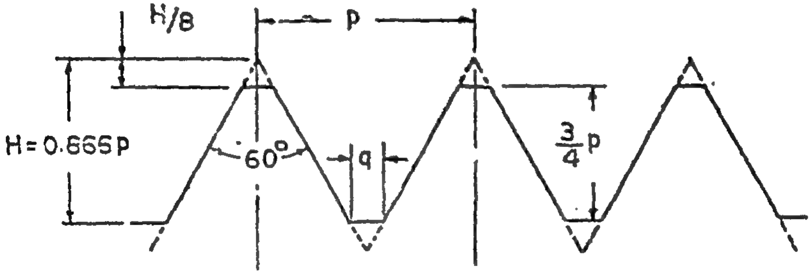
Effective or pitch diameter : It is the diameter at which the thread space and width are equal each being equal to half of the screw pitch [Fig. 21.1]

21.1.2. THREAD FORMS :

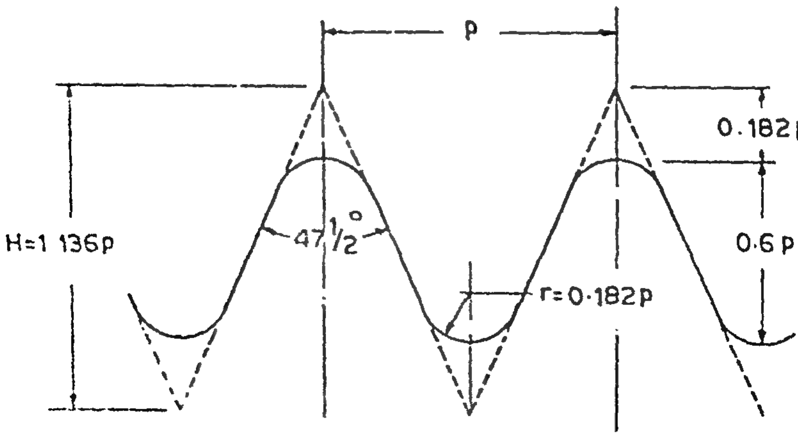
Screw threads having different forms and shapes are in common use. Some of the important thread forms are shown in fig. 21.2.

21.2. ERRORS IN SCREW THREAD.

Error in screw threads can arise during its manufacture or storage. These errors may be in major, minor or pitch diameter, thread form



(*a*) Metric System International thread



(*b*) B.A. thread

and the thread flank angle. The errors directly influence the functioning of screw threads. Let us examine the effects of various screw threads errors.

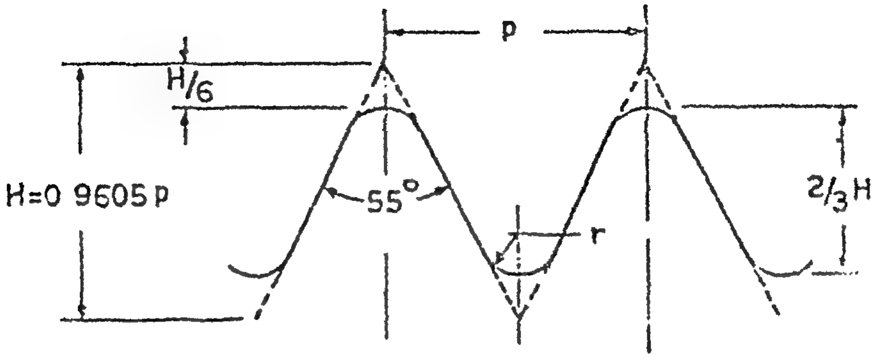
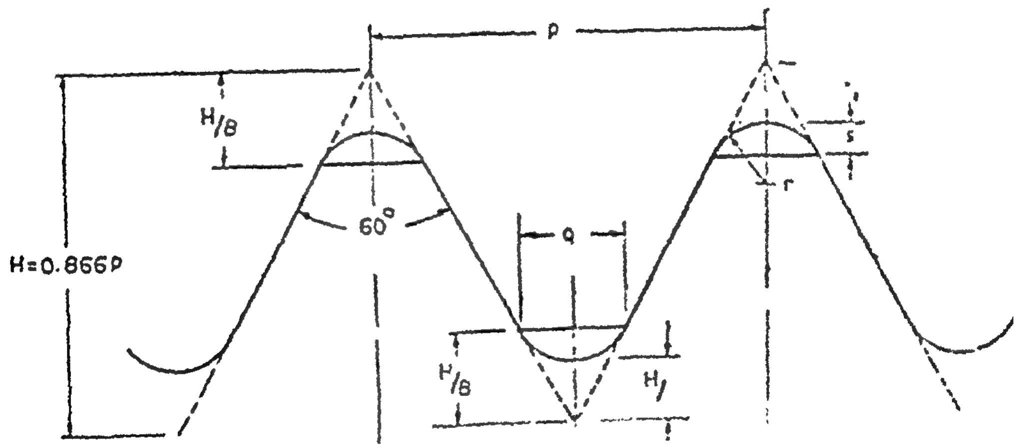


Fig. 21.2

(*c*) Whitworth thread.



(*d*) Unified thread.

Fig. 21.2

Errors in Major and Minor diameters

Error in either of the diameters would result into interference with the mating thread. Such a situation, if present, would lead to rapid wear and weakening of the screw thread,

A screw thread with defective pitch when assumbled with a nut would also cause interference. Fig. 21.3 shows a case in which the pitch of the screw thread increases progressively. Assuming that the pitch error is x. Correct mating of the screw and the nut can be obtained in this case by radial adjustment of the pitch diameter by an amount $y = x \cot \phi$. For a metric threads 2ϕ is 60° and hence for a pitch error of 'x' the radial adjustment in the pitch diameter would be $x \cot 30$ which is equal to $1.73\,x$.

Errors in the pitch of the screw threads can arise during

(*i*) The process of cutting.

(*ii*) During hardening, and

(*iii*) During storage.

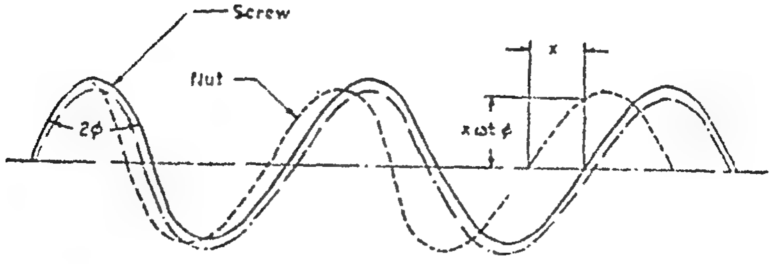


Fig. 21.3

Pitch diameter :

We have seen that an error in the pitch diameter of the screw thread would necessiate some adjustment in its pitch diameter in order to avoid interference. Therefore an error in pitch diameter itself would also cause interference during assembly.

Thread angle. : It can be seen that any error in the screw thread angle "2ϕ" would also require some adjustment in the effective pitch diameter so that no interference occurs during the assembly of the screw with the nut.

21.3 GAUGING OF SCREW THREADS.

The techniques used for the inspection of screw threads can be classified as

(*i*) Shop Measurement of the screw threads.

(*ii*) Direct Measurement.

21.3.1. Shop Mesurement of Screw Threds

The measurement of screw threads in the production shops is usually done with the help of thread gauges. The thread gauges used are :

(i) Ring screw gauges.

(*ii*) Plug screw gauges.

(*iii*) Thread callipers gauges.

(*i*) Ring Screw Gauge : This gauge is similar in principle to plain ring gauge except that it has screw threads cut on its inner surface. These gauges are used for checking screw threads on the outside of cylindrical objects such as the bolts, shafts etc. The gauge can be of go and not-go type. The go ring gauge has full

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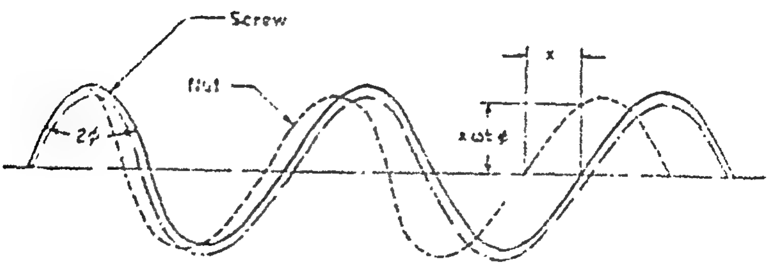

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thread form whilst the not-go ring gauge has threads truncated on the minor diameter.

Plug gauge : These gauges are avaiiable in a number of alternative designs. Such gauges would check the threads in the inside of a bore and are available in the go-not-go types.

Thread Callipers :

The thread calliper is similar in appearance to a snap gauge which is used for checking the outside diameter of the shafts. The difference between a snap gauge and the thread calliper being that the thread callipers have thread measuring jaws and the screw thread to be checked is mated with the jaws. Similar to snap gauges it is also of go and not-go design.

21.3 2. DIRECT MEASUREMENT OF THE SCREW THREADS :

The shop measurement techniques for the screw threads do not give any information about the amount of error in various elements of the thread. They simply accept or reject the threads produced. The direct measurement of the screw thread is useful means of knowing magnitude of error arising in the screw threads.

Measurement of major and minor diameters.

The major diameter of the screw threads and the minor diameter of the nut can be checked by the use of micrometer or verinier callipers as in plain diameter measurement.

Minor or root diameter of a screw thread can be measured by using a micrometer in conjunction with a pair of Vee blocks. The Vee blocks are designed such that they contact the root diameter of the thread and are placed diametrically opposite to and touch in the root diameter of the screw thread being checked [fig. 21.4].

The micrometer reading "D_s" over the Vee blocks when they are thus positioned in the screw thread is obtained. In order to eliminate the effects of the size of the Vee-block reading "D_R" of the micrometer is also obtained when the Vee blocks are placed diamentrically opposite to and touching a plug of known diameter Dp.

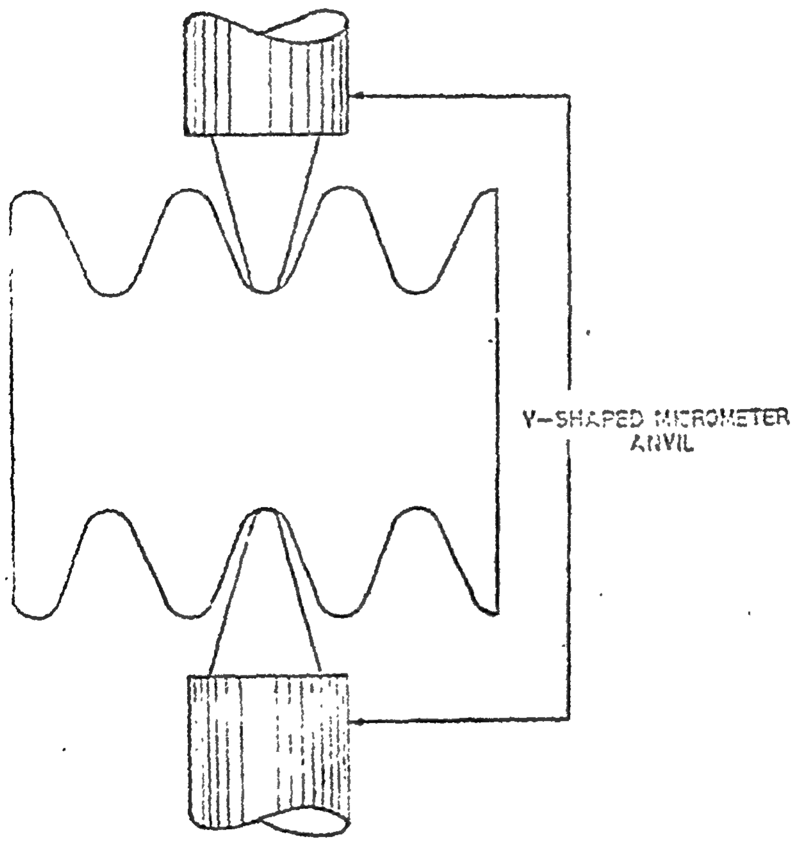


Fig. 21.4

The root diameter (D_r) of the screw thread is then given by

$$D_r = D_p + (D_S - D_R)$$

Pitch or effective diameter of screws threads could be measured by two or three wire method. Basically there is no difference between these methods. The two wire method is employed when floating carraige micrometer is available for the measurement purpose. With ordinary micrometers 3 wire should be used.

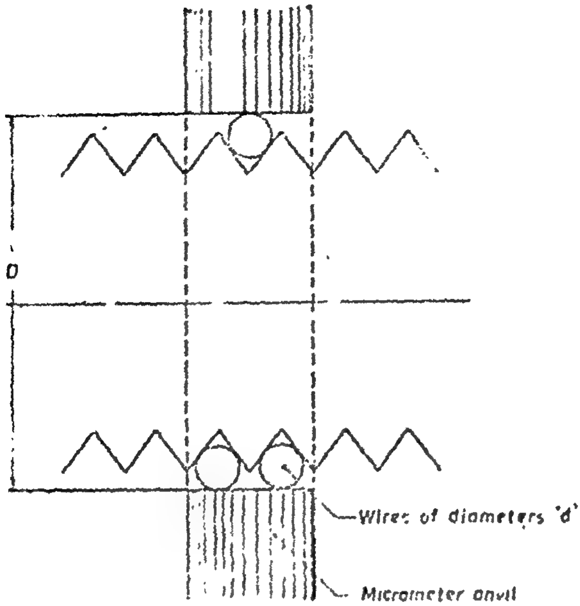


Fig. 21.5. Three wire method

In order to measure the effective diameter of a given screw thread three or two round wires (as the case may be) of equal diameters having a high degree of accuracy are placed in the thread grooves as shown in the fig. 21.5. The micrometer reading "D" over the wires is obtained. The effective diameter "D" of the screw thread can now be calculated from the geometry of the set up (Fig. 21.6).

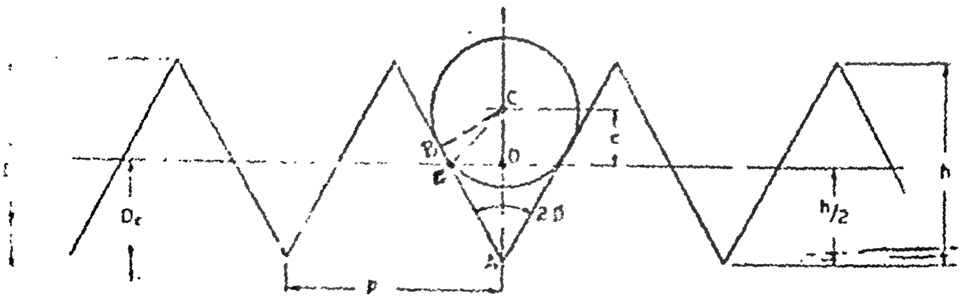


Fig. 21·6

From fig. 21.6 we get

$$AC=BC \quad \operatorname{cosec}\phi = \frac{d}{2} \operatorname{cosec}\phi \qquad \ldots(21.1)$$

also $AD=h/2$ ...(21.2)

but $h=p/2 \cot \phi$

hence, $AD=p/4 \cot \phi$ ...(21.3)

$$C=AC-AD$$

From (21.1) and (21.3), we get

$$C=\frac{d}{2} \operatorname{cosec}\phi - p/4 \cot \phi \qquad \ldots(21.4)$$

From fig. (21.6),

$$D=D_e+2C+d \qquad (21.5)$$

or, $$D=D_e+d(\operatorname{cosec}\phi+1)-\frac{p}{2}\cot \phi$$

using equation (21.5) the effective diameter D_e of the screw thread can be calculated provided the screw thread pitch "p", the thread angle "2ϕ" and the wire diameter "d" are known correctly.

For Metric threads $2\phi=60°$

Depth of the thread$=0.6495\,p$

Therefore $$D=D_e+d[\operatorname{cosec} 30°+1]-\frac{p}{2}[\cot 30] \qquad \ldots(21.6)$$

or $$D=D_e+3d-1.5155\,p \qquad \ldots(21.7)$$

The value of D for a given set up can be obtained experimentally and using the equation 21.6 D_e can be calculated for a given wire size.

The two or three wire method as described above will yield accurate results only when

(*i*) The thread angle ϕ is correct.

(*ii*) The screw thread pitch p has no errors.

(*iii*) The wire touches the straight portion of the tooth flank.

Selection of wire :

The wire diameter suitable for any particular screw thread should be such that the wire touches the thread on its straight portion only. Three extreme cases for wire size are shown in fig. 21.7.

The best wire size for the given screw thread is a wire having its diameter such that it would contact the screw thread exactly on the pitch point. The advantage of using wire of best size can be seen by examining the equation 21.5. For best wire size $C=0$ hence 21.5 reduces to

$C = \frac{P}{4}\tan\phi.\ \frac{d}{2}$

$$D = D_e + d(1 + \sin\phi) \qquad \ldots(21.8)$$

and under such conditions D_e is independent of the thread angle "ϕ". Table shows the best wire size for some of the common sorew threads.

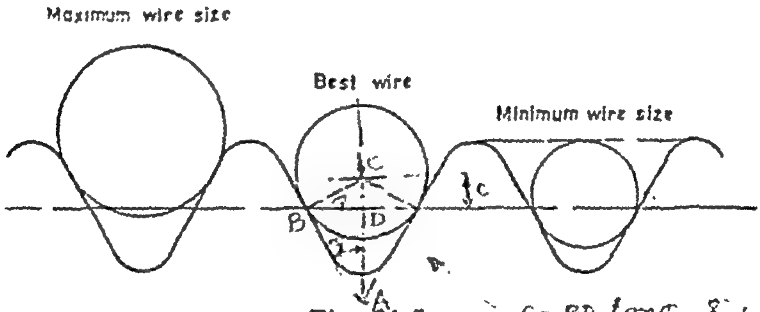


Fig. 21.7

$c = BD.\tan\phi$ & $c = BC. S$
$= P/4 \tan\phi$. $= \frac{d}{2} S$
$d = (P/2) \sec\phi$

Table at $\phi = 30$ $d = \frac{P}{2} \times \frac{2}{\sqrt{3}} = .577\,p$

Thread	Best wire diameter
American & Metric threads	0.577 p
Whit-Worth & BSF	0.564 p
B.A.	0.577 p

Pitch Measurement :

Pitch measurement of the screw threads can be done by

(i) Optical profile projection method

or by (ii) Pitch measuring machine.

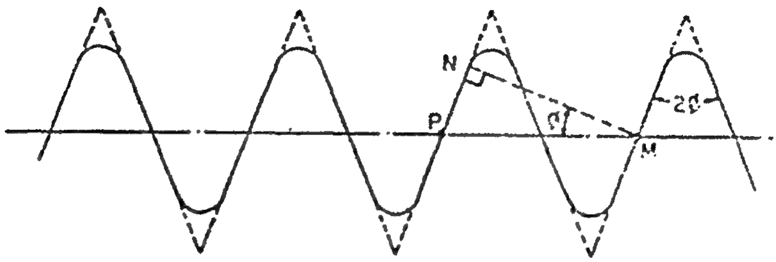


Fig. 21.8

Fig. 21.8 shows the profile of a screw thread projected by means of a profile projector. The pitch of the screw thread PM will be given by

$$PM = \frac{MN}{\text{Cos } \phi} \times \frac{1}{\text{Magnification}} \qquad (21.8)$$

MN, the length perpendicular to the thread flank can be measured experimentally and hence the pitch can be calculated from 21.8.

Measurement of Thread Angle.

The most convenient method of checking the thread angle is by projecting on image of the screw thread by means of a profile projector. However in order to obtain a satisfactory image it is necessary to project along the direction of the screw thread (fig 21·9) (*i.e.*, along the helix).

As the thread angle is measured (by definition) in plane of the screw thread axis hence certain amount of error in the measurement is liable to be introduced due to this condition. The amount of error can be calculated as follows.

Let β be the helix angle of the thread

h=depth of the screw thread.

$AB=EF\cos\beta=p\cos\beta$. ($p$=pitch of the thread)

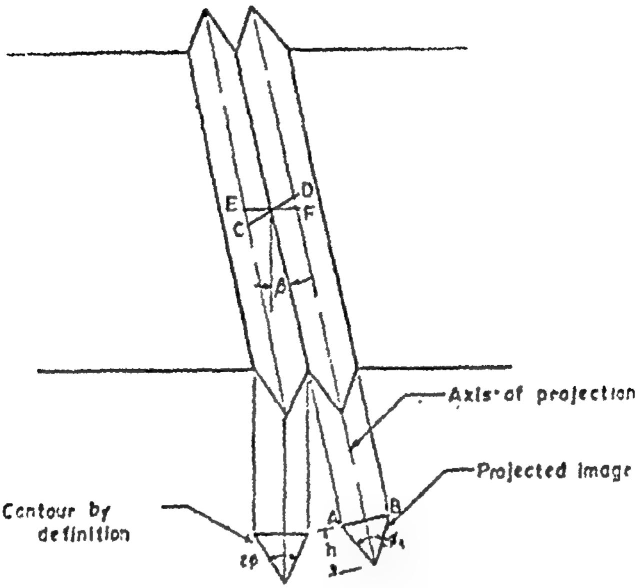


Fig. 21.9 Axis of projection

$$\text{Tan } \phi=\frac{p}{2h} \tag{21·9}$$

$$\text{Tan } \phi_1=\frac{AB}{2h}=\frac{p\cos\beta}{2h}$$

$$\frac{p\cos\beta}{\frac{2p}{2\tan\phi}}=\cos\beta\tan\phi$$

$$\text{or } \tan\phi_1=\cos\beta\text{ Tan }\phi. \tag{21·10}$$

Equation 21·10 enables us to calculate the amount of error arising in ϕ as a result of the helix angle. However it has been found that upto a helix angle of 5° the amount of error is too small.

21.4 INSPECTION OF GEARS.

Inspection of gear tooth is important so as to determine the quality of gears produced and also to provide a clue towards correct tool and machine setting during their manufacture. The elements of involutes spur gear tooth which need frequent checking are (*i*) Chordal tooth thickness (TD) (*ii*) Chordal base pitch (*iii*) Involute tooth profile and (*iv*) Pitch diameter. [See fig. 21·10]

21.4. MEASUREMENT OF CHORDAL THICKNESS.

Vernier tooth caliper is a common instrument for this purpose. In order to measure the chordal thickness of a given gear tooth the caliper jaws must be set at a distance "T_d" apart also the distance "a" must be set from the top at which "T_d" occurs. For any gear tooth the values "T_d and "a" can be calculated as follows :—

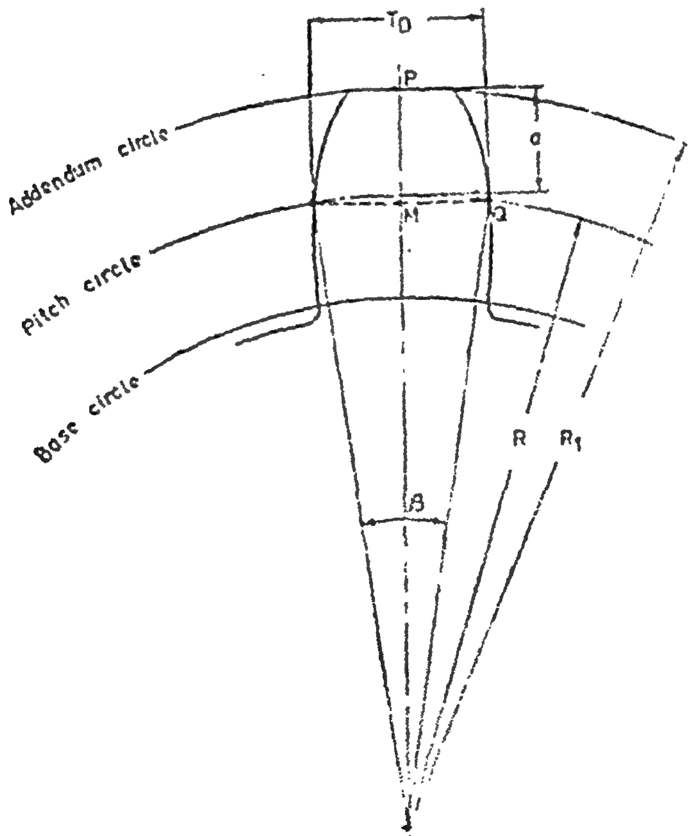


Fig. 21.10

Let M=Module of the gear

T=Number of the teeth in the gear being checked.

Referring to fig 21.10.

$$MQ=\frac{TD}{2}=R\sin\frac{90}{T}$$

$$\text{or, } TD=2R\sin\frac{90}{T}=M.T\sin\frac{90}{T}\left(\text{as } M=\frac{2R}{T}\right) \tag{21.11}$$

Also, we have $a=OP-OM$

$$=\frac{TM}{2}+M-OM$$

$$\text{but } OM=R\cos\frac{\beta}{2}=\frac{MT}{2}\cos\frac{90}{T}$$

$$\text{Therefore } a=M\left(\frac{T}{2}+1\right)-\frac{MT}{2}\cos\frac{90}{T}$$

$$\text{or } a=M\left[\frac{T}{2}\left(1-\cos\frac{90}{T}\right)+1\right] \tag{2.12}$$

using equations (21·11) and (21·12) for the given gear Vernier Caliper setting can be made. Any deviation in the measured dimensions of "T_d" and "a" from the set value will directly give the error.

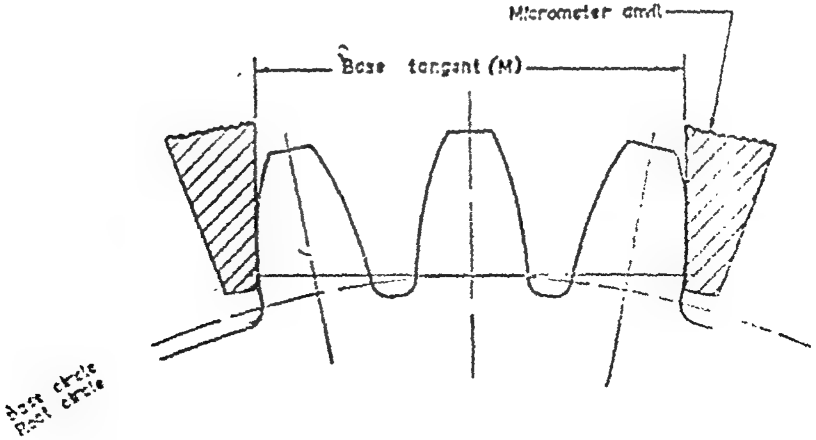


Fig. 21.11

21.4.2. MEASUREMENT OF BASE PITCH

Base pitch of a gear is defined as the circular pitch of the gear measured along the base circle. For a spur gear the base pitch P_b is given by

$$P_b = \pi M \cos \phi \qquad (21 \cdot 13)$$

Where M=Module of the gear

ϕ=Pressure angle

for helical gears

$$P_b = \pi\, M_n \cos \phi \qquad (21.14)$$

Where, M_n=normal module

The base pitch can be checked by measuring the distance between the tangents to the curved portions of any two adjacents teeth (fig. 21·11) As the gear tooth being checked is of involute form the distance between the tangent to the base circle, between two points, is equal to the length of the base pitch between those points.

A tangent micrometer is commonly employed to check the base pitch The distance between the micrometer jaws is set accurately by means of slip gauges, corresponding to the gear being checked. The micrometer jaws are now placed across the gear teeth as shown in fig 21·11. Any variation in the base tangent length over and above that of the set distance between the micrometer jaws can be read off.

21.4.3. Involute Testing.

An involute is a curve traced by 'a point P situated on a straight line AB, which is rolling without slipping over a circle of radius R. The involute traced by P is PP' (Fig. 21.12).

Simple form of involute testing machine consists of a disc "D" fixed to a spindle "O" which can rotate freely. (Fig. 21.13). The outside diameter of D is equal to the diameter of the base circle of the gear being tested. The gear "G" to be tested is also carried on the same shaft "O". The disc D is in firm contact with a straight edge "E" carried on by the movable carriage "C". The carriage "C"

can be moved in a straight line by operating the handwheel "H". AS the carriage is moved, the friction between the straight edge "E" and the disc "D" is sufficient to cause its rotation and hence of the

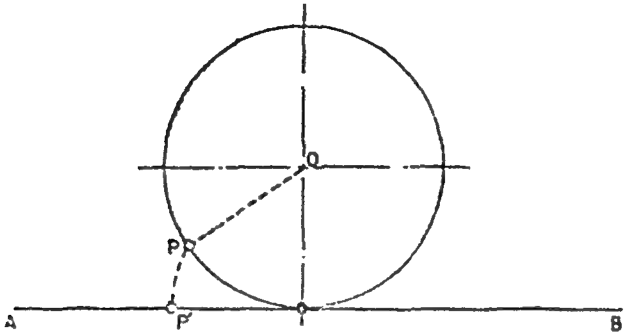


Fig. 21.12. Principle of Involute generation.

test-gear The carriage carries an arm "P" hinged in the middle. One end of the arm "P" contacts the tooth profile whereas the other

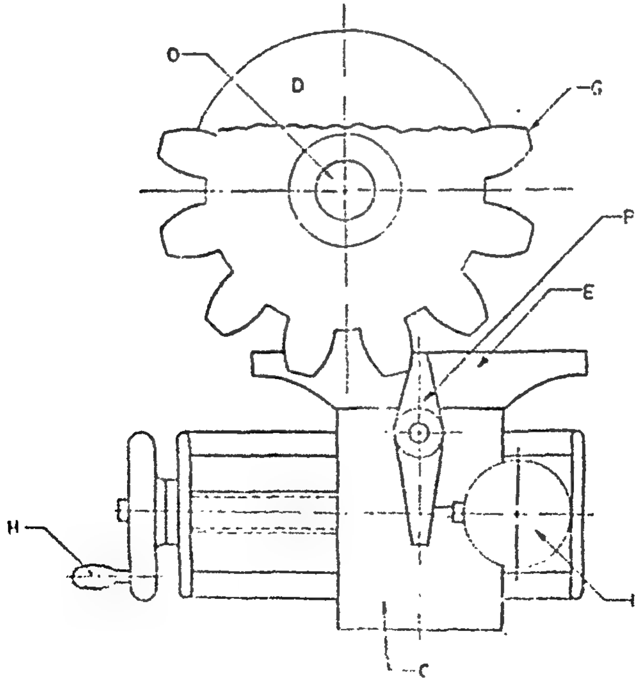


Fig. 21.13. Involute Testing Machine.

end operates a dial indicator "L". If the tooth profile of the gear being tested is a true involute then the dial gauge reading would remain constant as the carriage is moved causing D to rotate. Deviations of the tooth profile from true involute could be read-off by the dial gauge "L".

21.4.4. Measurement of pitch diameter.

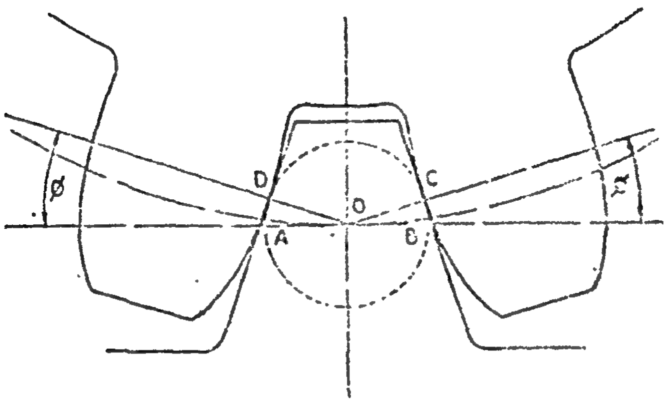


Fig. 21.14

Fig. 21.14 shows a gear tooth for which the pitch diameter is to be measured. By placing a pair of cylindrical plugs both of diameter $2 \times OD$ in diametrically opposite tooth spaces and measuring the distance X over the plugs the pitch diameter can be measured. The diameter of the plug which will rest in tooth space and lie with its centre on the pitch circle remains constant for all gears of the same pitch and pressure angle.

Calculation of the radius of plug required.

In triangle OAD, OD=radius of the plug

$$OD = OA \cos \phi$$

$$OA = \frac{\pi m}{4}$$ (m=module of the gear being checked)

Plug diameter required

$$2.OD = \frac{\pi m}{2} \cos \phi.$$

If the gear is of the correct pitch M the distance over the plugs should be equal to the pitch diameter of the gear being checked plus twice the radius of the plug used. The difference between the measured value of M and the calculated value would directly give the pitch error.

Quiz.

1. Define the following elements of a screw thread.

   (*a*) Pitch diameter (*b*) Flank angle (*c*) Root diameter and

   (*d*) Pitch.

2. Describe experimentally how the following could be checked :

   (*a*) Thread form (*b*) Pitch of screw thread (*c*) Root diameter.

3. Describe the common types of errors arising in screw threads. Indicate the sources of error and discuss the effect of these errors on correct functioning of the screws.

4. Explain giving suitable sketches how will you check the pitch diameter of gears. Derive any relationship you employ for this purpose.

5. Describe the principle of working of an involute tester. How will you use this instrument for actual checking of gears.

6. Describe suitable methods for checking (*a*) base pitch (*b*) chordal tooth thickness of gears. Give a list of equipments to be used. Derive any relation you would employ.

CHAPTER 22

ACCEPTANCE TESTS FOR MACHINE TOOLS

22.1. Scope :

Acceptance tests for machine tools help to specify its grade of accuracy, which in turn determines its working accuracy. In general the acceptance test for the machine tools can be divided into

1. Alignment test,
2. Performance test.

These tests can be applied equally to both new and reconditioned machines. The present day acceptance test procedure is mostly based on the Acceptance Chart first prepared by Dr. G. Schlesinger (1927). These charts specify the test procedure for various types of machine tools. The test chart for most of the machines are supplied along with the machine itself and specify the permissible alignment and working accuracy attainable in each case.

22.2. Common Instruments used in Alignment Test.

(*a*) **Dial gauge :** Dial gauge with magnetic base stand has been found to be satisfactory in most of the cases. The dial gauge graduations need not be finer than 0.01 mm. and the initial plunger pressure should vary between 40—100 gms. (1.5—3.502).

(*b*) **Test Mandrel:**

Mandrels are used extensively in machine tool alignment tests. The mandrel to be used must be as light as possible and must be straight and cylindrical to start with. It is common to use hardned mandrel accurately ground and stress relieved. The mandrel can either, be

(i) With cylindrical measuring surface having a tapered shank to fit into the tapered bore of the main spindle. Or

(ii) cylindrical mandrel which can be held between the centres.

The measuring length of the tapered shank hollow mandrels varies between 100—500 mm. (4—20 inches) and its diameter be such that the sag its own weight is kept down to within the permissible limits.

(c) Spirit Levels :

High precision spirit levels are quite common in acceptance tests. A sensitivity of 0.03—0.05 mm per 1000 mm for each division is recommended for this purpose. The bearing surface of the spirit levels be as long as possible and for medium sized machine tool testing the length of the spirit level bearing surface should not be less than 200 mm.

(d) Straight edges and squares :

The straight edges and squares used for the test can either be of cast iron or of steel. They must be of robust design and be free from internal stresses.

21.3. Test procedure

The steps involved in testing the machine tools consists of the following steps—

(i) Installation and levelling of the machine.

(*ii*) Testing the quality of guiding and bearing surfaces of the beds, vertical column etc.

(*iii*) Testing the main spindle for true running, axial slip and location with respect to other axes and surfaces.

(*iv*) Testing for determining the limits of accuracy.

(*i*) Installation and levelling

Before any of the tests are undertaken the machine in question should be properly installed using right type of foundation. The machine must be levelled as precisely as possible using precision spirit levels.

(*ii*) Testing the quality of guiding and bearing surfaces

No standards exist as far as the quality of guiding surface is concerned, however, procedure for the measurement of flatness, straightness and parallelism of the guiding surface have been fairly well established. One of the usual methods for checking the quality of the ground or scraped surface consists in moving the plunger of a dial gauge in a series of parallel straight lines. The stand carrying the dial gauge must be accurately located and guided. The radius of the dial gauge stylus tip to be employed should be of the order of 1.5 mm. This method would give the height and depth of peaks and valleys of the ground surface. The valleys of a well scraped or ground surface should not lie more than 2—5 micron below the main bearing surface.

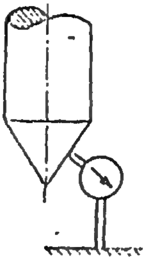


Fig. 22.1

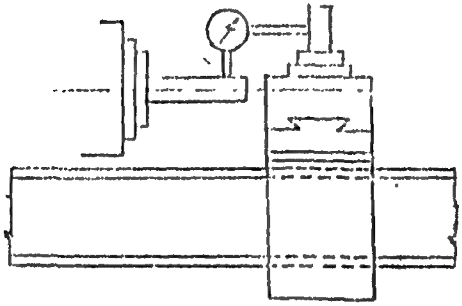


Fig. 22.2

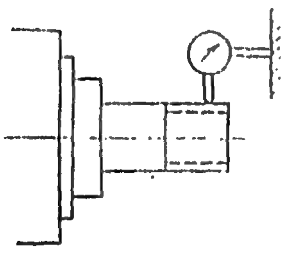


Fig. 22.3

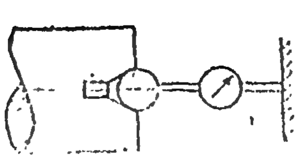


Fig. 22.4

(*iii*) Testing the main spindle for true running

In order to check the accuracy of main spindle and of their alignment relative to other important parts of the machine tool. The following tests are performed to check the

(*a*) True running of the centre.

(*b*) True running of the internal taper.

(*c*) True running of cylindrical locating spigots, external tapers, etc.

(*d*) Axial slip.

(*e*) Alignment between spindle axis and other axes.

(*f*) Perpendicularly between spindle axis and slideways.

It is important to note that the alignment tests must be performed under the normal running conditions so that the bearings have assumed the usual running temperature.

True running of the centre can be checked by means of a dial gauge (fig. 22.1). The test will reveal whether

(*i*) The spindle axis is inclined to the axis of rotation.

(*ii*) The spindle axis is eccentric with respect to the axis of rotation.

and (*iii*) Lack of roundness in the surface being tested.

The test for true running of the centre point fig. (22.1) is usually recommended for lathes boxing and cylindrical grinding machines. In case of machines with rotating spindle, *e.g.*, lathe, grinding machines, milling, drilling m/cs etc. a test mandrel with tapered shank is to be used (fig. 22.2). The dial gauge stylus rests

on the cylindrical surface of the test mandel and the dial gauge readings are recorded whilst the spindle is rotated slowly. Readings are taken near the two ends of the test mandrel at the points x & y. External rorating cylindrical shafts are used in machine tools for a number of cases, *e.g.*, for locating a grinding wheel, milling cutter, chuck of a lathe etc. The true running of such shafts could be checked by the method illustrated in fig. 22.3. The dial gauge readings are taken whilst the spindle is rotated slowly.

Axial slip is defined as the total spindle movement in the axial direction. This movement is liable to repeat itself in each revolution and is caused due to errors in the thrust bearing. There is a difference between the axial slip and end play. The later is due to axial clearance provided in the spindle bearing for its easy movement. It is therefore essential that the axial slip be measured under an axial applied thrust. The method for measuring the axial slip of a shaft is shown in fig. 22.4.

Alignment

Alignment between two axes such as that between the head and tailstock of a lathe, centres of a cylindrical grinding machine etc. can be checked using standard test mandrels and a dial gauge. Dial gauge readings are taken at 180° positions in horizontal & vertical planes. The alignment error would be equal to half of the two opposite dial gauge readings (Fig. 22.5).

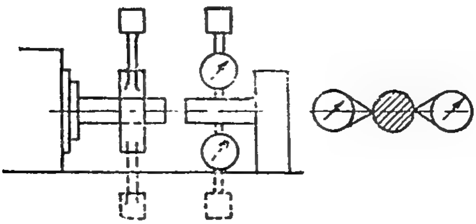


Fig. 22.5

Parallelism

Parallelism between two axes or between an axis and a surface can be checked by measuring the distance between them at different points. Parallelism is usually checked in both horizontal and vertical planes. (Fig. 22.6).

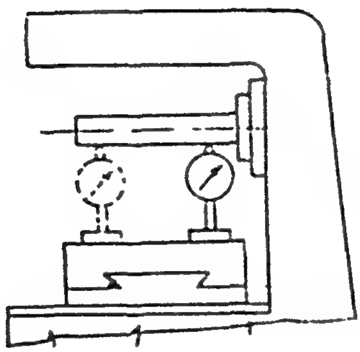


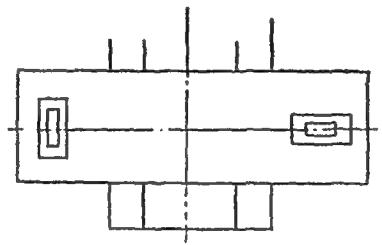
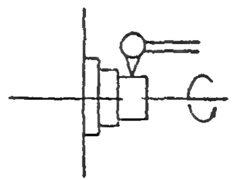
Fig. 22.6. Checking the parallelism of milling machine table and spindle axis.

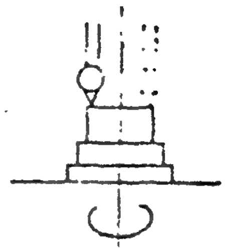
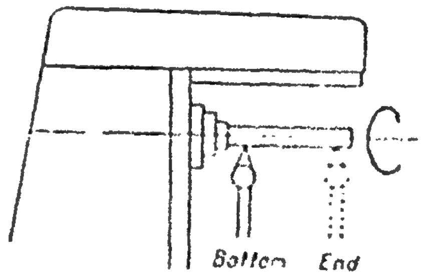
22.4 Detailed test chart

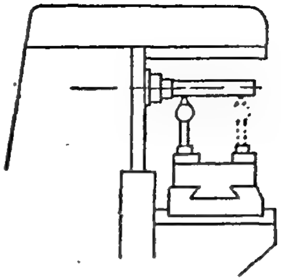
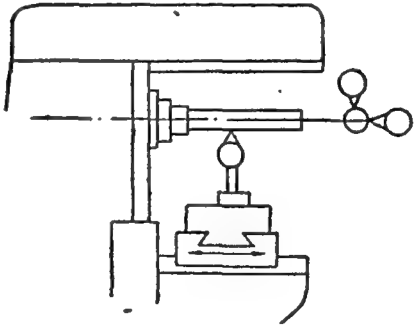
ISI, and other Standard Institutions have prescribed standard test charts for different types of machine tools in detail. Test chart for a milling machine is given in the table.

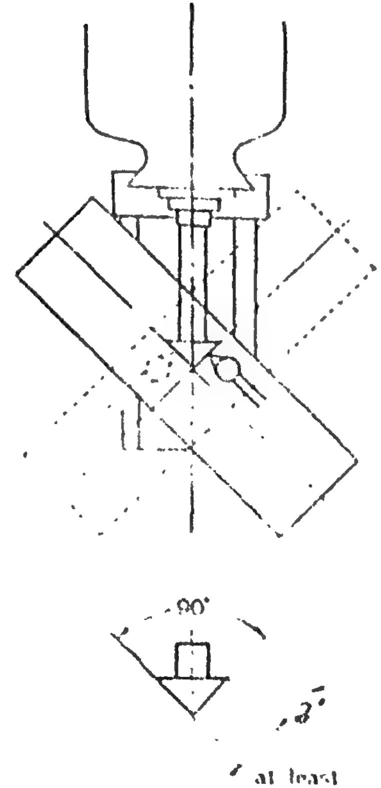
TABLE

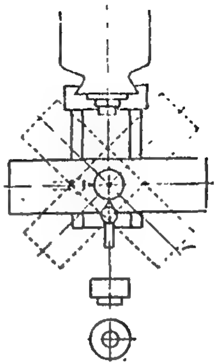
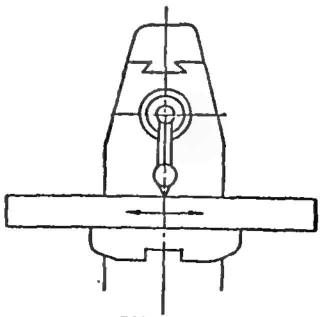
Acceptance Test Chart for Milling Macaines

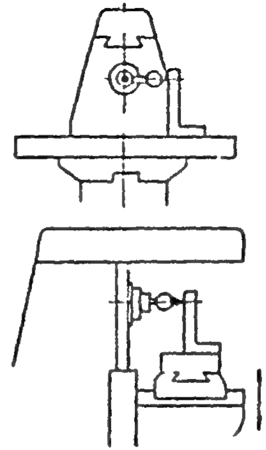
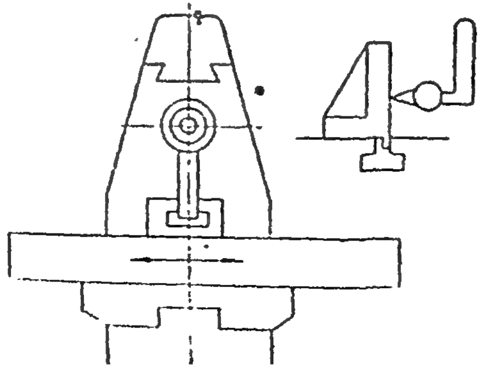
No.	Test to be Applied		Method	Figure	Permissible Error
1.	Work table that or level	Longi-tudinal direc-tion	Place table at middle center of all movement directions. Place level on surface of the table.		Table movement 500,1000 mm 0.060—0.10 mm
		Cross direc-tion	Read ievel at least 3 places on the table. The largest difference is test value.		
2.	Spindle periphery run-out		Place indicator point at periphery of spindle. Read while rotating the spindle. Largest difference is test value.		0.01 mm.

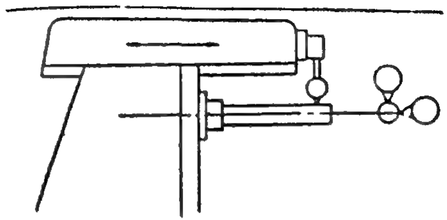
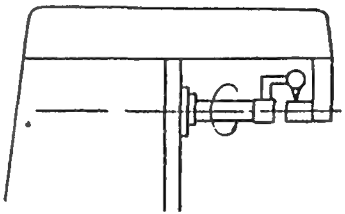
No.	Test to be Appied	Method	Figure	Permissible Error
3.	Spindle end face run-out	Place test indicator point to touch edge of the spindle and face. Read indicator while turning the spindle. Largest difference is test value. Double check, shifting indicator to opposite side of the spindle face.		0.02 mm
4.	Spindle hole run-out	Insert test bar into spindle hole. Read indicator pointing it at two places on the bar while turning the spindle. Largest difference is test value.		Test bar bottom 0.01 mm end 0.02 mm. 30 mm

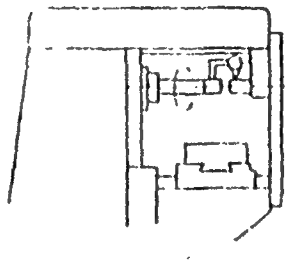
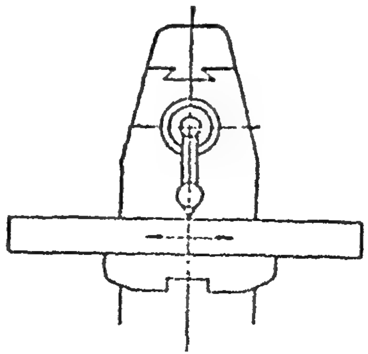
No.	Test to be Applied		Method	Figure	Permissible Error
5.	Table top surface parallel with center line of spindle		Position table at middle center of longitudinal movement direction. Insert test bar into spindle hole Read indicator at two places on the bar. Largest difference is test value.		0.02/300 mm Low point must be at rear.
6.	Table.s cross mouement parallel with spindle's center	Vertical plane	Position table at middle center of longitudinal movement direction install securely indicator on the table. Let indicator's point touch the test bar inserted into spindle hole. Read indicator while moving the table in cross direction. Largest difference is test value.		0.020/300 mm Low point must be at rear.
		Horizontal plane			0.02 mm/300 mm

No.	Test to be Applied	Method	Figure	Permissible Error
	Axis of swivel carriage offset with respect to cutter spindle	Insert test bar into spindle hole. Position table 45° slant against spindle center liner. Place test indicator on the table so as the indicator positions level with spindle's center line; Fix indicator at the position and read leting indicator's point touch cone of the test bar. Then turn table 90° to let indicator point touch opposite face of test bar cone, the difference of reading multiplied by $0.7 (=1\sqrt{2})$ is test value. Provided : The position of spindle's center line against the table should be such the test indicator's point (which was leveled to the same height as the spindl center line) would not tremble (or fluctuate) when table was moved to feeding direction keeping indicator's point touched to cone of		0.05 mm (Reading of indicator) 0.07 mm

No.	Test to be Applied	Method	Figure	Permissible Error
8.	Center T slot at work table offset with respect to cutter spindle	Place table to square with spindle. Fix circular rular on table center T-slot Place test indicator to front or rear of the ruler. Match the reading at 45° turned one way and 45° turned reverse way, where the indicator will be fixed securely. Then proceed. Similar measurement letting indicator touch at the left or right side of the ruler. Reading on indicator multiplied. $0.7(\div 1\sqrt{1})$ is test value.		0 05 mm (Reading of indicator 0.070 mm)
9.	Table's longitudinal movement parallel with table top surface	Fix test indicator on (for instance) spindle or over-arm. Let indicator point touch table top surface. Read while moving the table over all its movement length. Largest difference is test value.		Table movement under 500 mm : 0.02 mm Do under 1000 mm : 0.03 mm Do under 1000 mm 0.04 mm

No.	Test to be Applied		Method	Figure	Permissible Error
10.	Knee vertical move-ment square with table top	In a plane parallel with column	Position table at middle center of longitudinal and cross movement directions Install square ruler on top of it. Fix test indicator on (for instance) spindle or overarm, extending its point to the ruler. Read indicator : at lowest position where knee slide down on column way and clamped and another position upward and clamped as much as a measuring distance. Largest difference in reading in reading is test value.		0.02 mm/300
		In a plane square with column			0.02 mm/300 mm Low point must be at rear.
11.	Table's longitudinal movement parallel with center T-slot		Place square ruler on top of table, letting its project touch at vertical face of T-slot. Fix indicator on (for instance) spindle or overarm, so as to keep contacted with the vertical face of square. Read indicator while moving table and square ruler. Largest difference over all length of movement in [illegible]		Table movement under 500 mm : 0.02 mm Do under 1000 mm : 0.03 mm Do over 1000 mm : 0.04 mm

No.	Test to be Applied		Method	Figure	Permissible Error
12.	Overarm parallel with spindle center line	In vertical plane	Insert test bar into spindle hole. Fix test indicator on cverarm, extending its point to he bar. Read indicator while moving overarm. Largest difference read when it was fastened securely is test value.		0.02 mm/300 mm
		In horizontal place			0.02 mm/300 mm
13.	Alignment of arbor supports with spindle		Insert test bar into arbor support hole Fix indicator on spindle letting its point touch at the bottom. The half of the largest difference of reading in spindle's revolution is test value.		Distance between arbor support and spindle front end 300 mm 0.02 mm Distance 400 mm—0.003 mm

No.	Tesr to be Applied	Method	Figure	Permissible Error
14.	Alignment of arbor supports with spindle (in case bracce was clamped security)	In case machine has brace, use it. Reading be done in same way as shown in item 14, provided all braces were clamped.		Distance between arbor support and spindle front end 300 mm 0 02 mm 400 mm—0.03 mm
14.	Total pitch error of screw in table's feeding	Place table at least at 3 places, middle center and both ends. Screw slowly and screw feeding by. hand. Measure error between actual move and supposed move by end scale of certain length and test indicator. Provided : Test may be omittted for the feed screw which has been tested by other tester of equivalent standard.		0.07 mm/300 mm

CHAPTER 23

SYSTEM OF LIMITS & FITS

Concept Of Interchangeability

In the present type of production system it is a well accepted fact that there is no necessity of making the components to the dimensions indicated on the drawings produced by designers. It has been realised that perfect components are difficult to produce and any attempt towards perfection will amount to extra cost of the product. The functional aspect of the component can be achieved even without going for its exact dimension. This, then, becomes one of the ways to increase the rate of production and reduce the unit cost of the product. This means a *predetermined variation* in the basic dimension of a product will bring down the unit cost.

When the assembly of two mating parts is considered this kind of permitted variation assumes a very important significance. Consider a situation where a large number of pairs of mating parts (say a shaft and a bearing) are being manufactured, each with a predetermined variation in diameter. If any shaft and bearing picked up randomly from their respective lots are assembled to give a desired assembly then this kind of production is referred interchangeable production. This forms the main basis of the present day mass-production system in the industries and is known as principle of interchangeability. Interchangeable production means the production of parts to such a degree of accuracy that will ensure an assembly which will meet the functional requirements. It can therefore, be said

(*i*) the assembly of the mating parts is easier since any component picked up from its lot will assemble with any other mating component from the other lot without additional fitting and machining.

(*ii*) it brings down the assembly cost drastically.

(*iii*) the replacement of the damaged part can be easily procured.

(*iv*) the standardisation of machine parts and manufacturing methods is decided.

(*v*) it enhances the production rate.

Basic Size

The basic size of a component is fixed up by the designer from its functional considerations. Such dimensions are very difficult to maintain during production for a large number of reasons such as human factors, wear of the processing tools and machine and quality of the raw material. A rigid attitude towards the maintenance of the basic size shall increase the cost of production. The production engineer, therefore, wants a little variation in dimensions during production. In other words a little error in dimension is tolerable. Let the error be called *tolerance*. The other term used with respect to the component is nominal size. As a matter of fact nominal size is used for general purpose identification of the component and is never used in the precision measurement science.

Tolerance. The tolerance is therefore, predetermined variation on the nominal dimension of the product. It indicates how much a part may deviate from its nominal or basic dimension and still function properly. The variation can be on one side or on the both. For example

(*i*)	(*ii*)	(*iii*)
$25\pm^{0.035}_{0.000}$	$25\pm^{0.000}_{0.026}$	$25\pm^{0.035}_{0.026}$

The tolerances as indicated in cases (*i*) and (*ii*) are called unilateral tolerances and case (*iii*) is called bi-lateral tolerance. It is not necessary that in the case of bi-lateral tolerance the variation should be equal. Wider tolerances give more economy whereas closer tolerances increase the production cost.

Limits

The tolerances when added to basic size provide the maximum and minimum dimensions of the product. As long as the product, are being manufactured within this range, they are acceptable. The maximum dimension is called upper limit and the lower dimension is called the lower limit. In the first case of the above example, the upper limit is 25.035 mm and the lower limit is 25 mm. The limits are helpful in deciding the type of 'fit' between two mating parts. This makes the design of a limit system pertaining to an assembly of the components very complex. Narrow and wide limits are decided mainly upon the functions of the assembly and therefore, the design is done very careful. Other consideration's taken into account are the quality of the work, type of the machine tool and the skill of the worker.

Clearance & Allowance

The terms clearance and allowance are used in conjunction with the type of fit required in the assembly. Referring to a simple

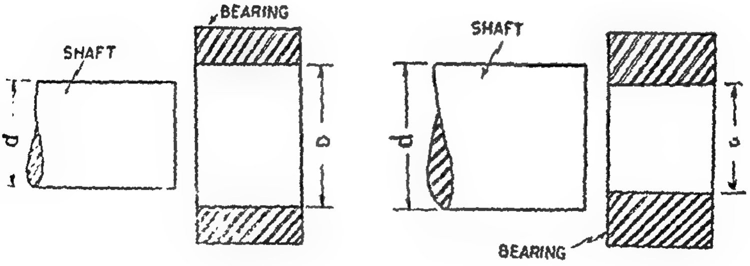


Fig. 23.01

assembly of a shaft and bearing, fig. 23.01 the clearance is (D—d). In the first case the value is positive while in the other it is nega-

tive. The negative clearance has been termed as interference. In this case the shaft diameter interferes with the hole diameter and to achieve the assembly extra force is needed.

Since both, the diameters have upper and lower values hence there are two values of clearance. They are maximum clearance and minimum clearance and similarly, maximum interference. The minimum clearance and maximum interference is called allowance. These terms have been expressed on the diagram (23.02).

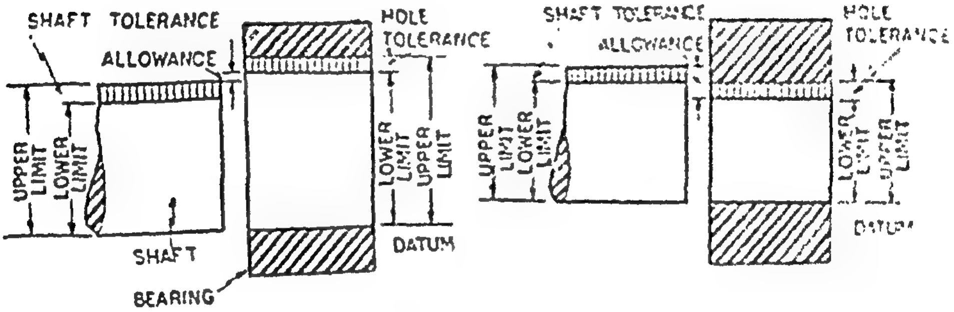


Fig. 23.02

Fits

On the basis of positve, zero and negative values of the clearance, there have been developed three major kinds of fits—clearance fit, transition fit and interference fit. These have been further sub-classified in the following manner.

Clearance fit

(*i*) Loose fit —This kind of fit is employed between those mating parts where no precision is required such agricultural & farm machinaries, hand trollies for transporting materials, certain types of transmission units of textile machinaries, plumer block bearings and loose pulleys.

(*ii*) Free fit —This fit provides less allowance and is used in bearings in oil engines, automobile parts, electric motors and generator where there is considerably large relative motion between parts.

(*iii*) Medium fit—It offers minimum allowance between the mating parts and hence offers great precision in the movement of the parts. It is used on machine tools slides and Jig bushes, for piston and slide valves.

Transition fits

(*i*) Snug fit —This fit refers to zero allowance between the mating parts and requires a very careful hand assembly. It is also known as push fit. The moving parts will show least vibrations.

(*ii*) Wringing fit—When there is very slight negative allowance it is termed as wringing fit. This assembly requires the application of tapping force and gives a tight assembly. Examples are fixing keys, dowels and pints.

Interference fit

(*i*) Tight fit —The negative allowance is higher than before. A light pressure is needed to bring out the assembly. It is employed in those cases where the part is to be maintained in position during running canditions such a pulley on a key and shaft, rocker arm, etc.

(*ii*) Medium force fit—The negative allowance is quite appreciable and therefore, assemble is obtained only when high pressure is applied. This fit offers a permanent type of assembly.

(*iii*) **Heavy force and shrink fit** ; It refers to maximum negative allowance. Heavy force is necessary for the assembly. The fitting of frame or rim can also be obtained firstly be heating the frame and then rapidly cooling it in its position.

TABLE

ASA Recommended formulas for Allowances and Tolerances

Interchangeable Assembly	Fits	Minimum clearance	Hole Tolerance	Shaft Tolerance
	Loose	$.0025\sqrt[3]{d^2}$	$+.0025\sqrt[3]{d}$	$-.0025\sqrt[3]{d}$
	Free	$.0014\sqrt[3]{d^2}$	$+.0013\sqrt[3]{d}$	$-.0013\sqrt[3]{d}$
	Medium	$.000\sqrt[3]{d^2}$	$+.0008\sqrt[3]{d}$	$-.0008\sqrt[3]{d}$
	Snug	.000	$+.0006\sqrt[3]{d}$	$-.0004\sqrt[3]{d}$
Selective Assembly	Wringing	.000	$+.0006\sqrt[3]{d}$	$+.0004\sqrt[3]{d}$
	Tight	$.0005d$	$+.0006\sqrt[3]{d}$	$+.0006\sqrt[3]{d}$
	Medium force	$.0005d$	$+.0006\sqrt[3]{d}$	$+.0006\sqrt[3]{d}$
	Heavy force	$.001d$	$+.0006\sqrt[3]{d}$	$+.0006\sqrt[3]{d}$

Selective Assembly

In the earlier part of this chapter it has been explained that interchangeability means the assembly of two random selected mating parts. When interference exists between the dimensions of the mating parts interchangeability cannot be relied upon because a constant interference will not be obtained. Let us understand this with the help of an example of a shaft and pulley where a constant interference of 0·25 mm. is desired. The diameter of the bore is $100\pm^{0.20}_{000}$ and that of shaft is $100.2\pm^{0.20}_{0.00}$. Let the following be any four random combinations.

Bore of Pulley	100.00	100.10	100.200	100.10
Shaft	100.20	100.40	100.200	100.40
Interference	0.20	0.30	0.000	0.30

Only in one case the required interferference is available or this indicates that if interchangeable assembly is adopted there are chances of having assemblies with different interference. To achieve the objective the assembly method has to be modified or it should be done on selective basis. Assuming the same diameters of pulley the shaft has to be selecte for the required assembly in the following manner.

Bore of pulley	100.00	100.10	100.20	100.10
Shaft	100.20	100.30	100.40	100.80
Interference	0.20	0.20	0.20	0.20

If we carefully look on the figures shown in the second stage it could be said that larger shaft has been selected for larger diameter and smaller shaft has been selected for smaller hole. This procedure is called selective assembly and is applicable only in the case of interference or where toe allowances are minimum. The use of selective methods of assembly in interchangeable manufacture is also referred as zoning assembly.

System of Fits

Two very common systems of fits have been developed on the hole-basis and shaft-basis. These are called as 'Basic Hole System' and 'Basic Shaft System'.

In the case of hole system the size of the hole is kept constant and the shaft size is varied to obtain varions classes of fits. Similarly in the case of shaft basis system the size of the shaft is kept constant and the variation is only done in the hole size to obtain various fits. The hole system is preferred over shaft system for various reasons of economy.

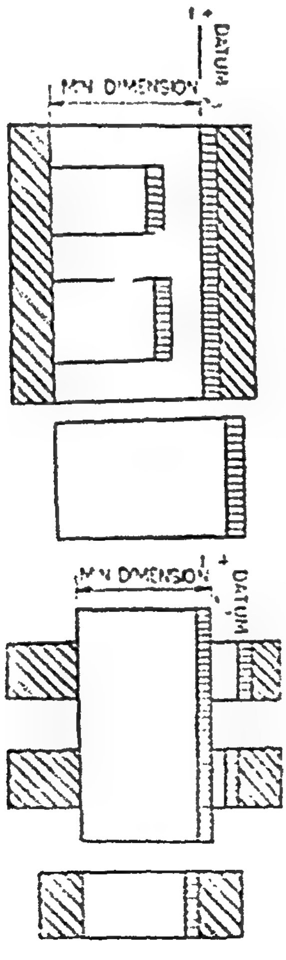


Fig. 23.03

The following is a brief description of the uses of various grades of the unilateral hole H from H5 to H11 as prescribed by I.S.I. standards.

H5—This grade is obtained normally by precision boring, fine internal grinding and honing.

H6—This grade is capable of being produced by precision boring and honing or possibly by hand reaming.

H7—This hole may be produced by grinding, broaching or careful reaming.

H8—This grade may be produced by boring or machine reaming,

H9—This grade may be obtained by boring and reaming and is mostly used for non-circular fits.

H10—This grade is also not used for diameter fits. Ii is used for milled widths and unimportant parts on drilled holes.

H11—This grade is normally not used in fits. It is useful for coarse drilled, punched or pressed holes.

Another system quite often encountered in the shops is known as the Newall System after the name of its originator I. Newall.

QUIZ

1. Explain the terms interchangeability and mass-production.
2. How do you distinguish between tolerance and allowance ?
3. Why limits are necessary ?
4. Define Fits and bring out a classification of fits.
5. Describe selective assembly.

CHAPTER 24

DESIGN OF LIMIT GAUGES

Components that are to be assembled to make a product have their mating dimensions manufactured to a determined accuracy. This occuracy greatly reflects itself in the cost of the product. To stress on accuracy greater than necessary for the product makes the project uneconomical. Therefore all mating dimension are provided with limits *i.e.* high limit and low limit of dimensions. The difference between the high limits and low limit of a dimension is called the dimensional tolerance. The tolerance for a particular dimension depends upon the nominal size of the dimension and the fit required. The tolerances as also the high and low limits are determined by consulting standard of limits and fits. I.S.I. 889 specifies the high and low limits for dimensions for the type of fit desired.

Once the tolerances for a particular component have been determined, the next thing to be considered is the control and maintenance of tolerances within the high limit and low limit of each tolerance. The operator on the machine constantly tries to manufacture components within the tolerance with the help of guages and measuring instruments. The parts so manufactured are further checked by inspection department with the help of more accurate gauges and measuring instruments. However in a repetition work it is not possible to check dimensions with the usual precision instruments like micrometers, verniers etc., especially where unskilled and semiskilled labour is employed. Hence in shops engaged in mass production where interchangeability is also to be secured at as low a cost as possible the dimensional tolerances within the high and low limits are controlled by :—

1. Limit gauges.
2. Indicating gauges.
3. Combination gauges.

A gauge is thus, a device for determining the relative size or shape of a component. It determines whether the part is inside or outside the tolerance zone. Measuring instruments which cannot be dispensed with in tool room work ; however determine what size or shape the component actually is. Gauges are generally referred to as fixed gauges. It is due to the fact that the fixed gauge is tied to a particular operation and in most cases is built in the plant where the gauge to be used. Advantages of suitable gauging system can be listed as :—

1. Semiskilled operators can control the dimensions within limits with the help of limit gauges.
2. The time to inspect at shop floor is largely minimised.
3. Interchangeability is secured at a very low cost and components can be assembled without difficulty.

Only disadvantage that can be connected with gauging system is that apart from giving up idea about the exact size, the gauges indicate nothing about the trend of size when the size is increasing or decreasing till the gauges start rejecting. Then only the corrective measures such as resetting are resorted to.

Classification of gauges :

Gauges can be conveniently classified in two ways 1. according to the principle of manufacturing, 2. according to function they perform. According to the first classification they can be placed in three broad groups namely 1. Fixed limit gauges, 2. Indicating gauges and 3 Combination gauges.

Fixed limit gauges are the most common and are used for both large and small production. Most of these are standard gauges. However the tool designer is frequently given the job of designing simple limit gauges for special work. These gauges can be further subdivided into ring gauges, plug guages, screwing gauges and depth gauges etc.

Indicating gauges are comparatively complex. They can be defined as device for accurately and quickly indicating on a visual

scale one or more dimensions of a work piece. There are many types of both special and standardised indicator gauges. The most common is the dial gauge used extensively in a mechanical comparator. Dial gauges need the designing of a suitable fixture for easy control of a dimension. All indicator gauges incorporate some sort of magnifying device. For control of a dimension the needle should remain between two preset marks.

Combination gauges are special devices designed to measure or check more than one dimension of a work piece at a given set up.

According to second mode of classification the gauges can be classified as follows :—

1. Inside dimensions
   (*a*) Plug gauges.
   (*b*) Piu gauges.
   (*c*) Bore indicators.
2. Outside dimensions
   (*a*) Ring gauges-
   (*b*) Plate or adjustable snap gauges.
   (*c*) Indicating snap gauges.
   (*d*) Built up snap gauges.
3. Offset dimensions
   (*a*) Plate gauges.
   (*b*) Flush Pin gauges.
   (*c*) Indicating gauges.
4. Gauges for location and concentricity determinations.
5. Gauges for taper determinations.
6. Gauges for profile determinations.

Internal limlt gauges :

Both plug and pin gauges are internal limit gauges. Each may consist of two separate members. One member is called the go member and the other the No go member. Again they may consist of only one piece, ane end forming the go member and the oth No go member.

Thus a plug gauge usually consists of two parts, the gauging member and a handle, with the size Go or Not Go and the gauge makers tolerance marked on it. Standard plug gauges generally have three methods of mounting the gauge members on the handle. The smaller sizes are usually ealled wire type gauges. The gauge member is simply a straight blank with no shoulder, taper or threads. The gauge member on this type is held in the handle by a set screw or with a collet type chuck built into the handle. Another type of mounting is called the taper lock design, In this type the gauge member is manufactured with a taper ground on onc end. The taper fits into a tapered hole in the handle. The third type is the tri lock design. This type is usually for larger size gauges. The gauge member has a hole drilled through the centre and is counter bored on both ends to receive a standard socket head screw. Three slots are milled radially in each end of the gauge member. The gauge is held to the handle by means of a socket-head screw with the three slots engaging three lugs provided on the end of the handle.

The Go and No Go ends of plug gauges generally vary in length. The Go end is always longer. The reason for this is that the Go end goes into the hole and its front position is likeiy to wear out. The Not Go end must not enter and is not likely to wear out soon. When gauging blind holes, it is essential to provide air vent in the plug gauge. For ease in positioning and engaging in close fit holes the pilot must be designed in the front end of Go side of plug gauge,

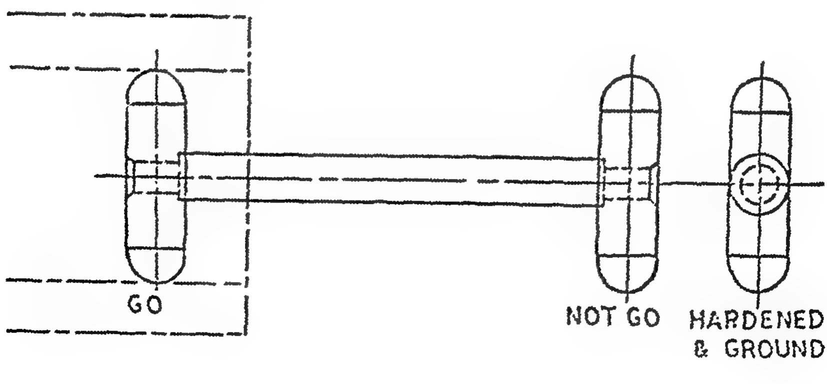


Fig. 24.01. A pin gauge

in larger bore plug gauges also it is desirable to reduce the weight of the gauge by drilling holes in the gauging members.

When the hotes are large. than 75 mm. such as automobile cylinders, plug gauges become very heavy. In these cases, it is convenient to use pin gauges (Fig. 24.1). In using a pin gauge, the gauge is placed lengthwise across the cylinder bore and the measurement is made in a manner similar to that of an inside micrometer. Pin gauges are specially useful in measuring the width of slots or grooves. Special plug gauges are sometimes, designed to check hales with serrations or involute gear teeto. Fig. 24.2.

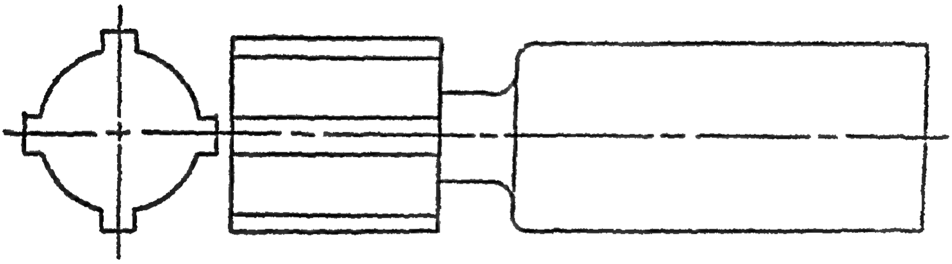


Fig. 24.02. Special gauge

External limit gauges :

They are used for measuring external diameters and thicknesses. They are of two rypes Ring gauges and Snap gauges. Other names for snap gauge may be caliper gauge or gap gauge.

Ring gauge is counter part of the plug gauge. Ring gauges are usually used in pairs, consisting of go member and a no go member. They are fixed type gauges and their design is covered by American gauge design standards. Ring gauges are not much used as the operation of the ring gauge Fig 24.3 is relatively slow as compared to a snap gauge.

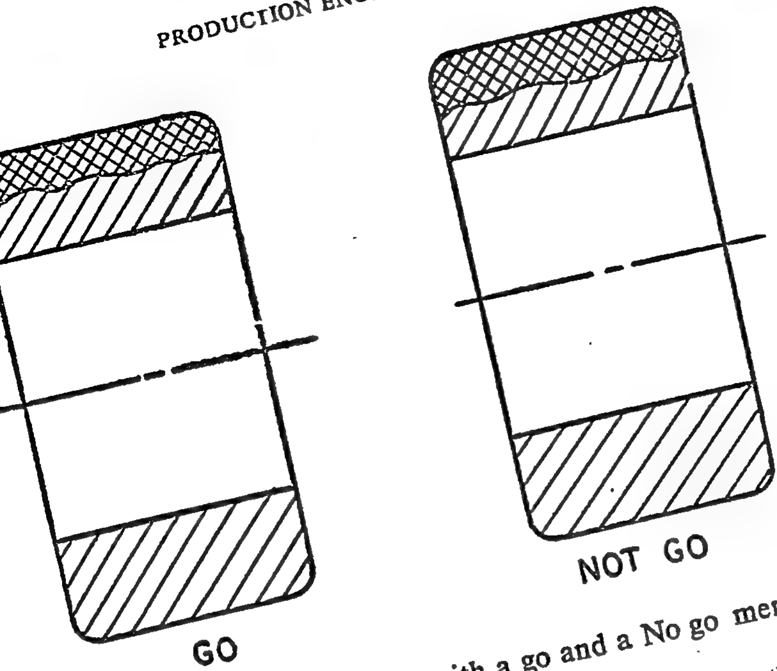


Fig 24.03. A ring gauge with a go and a No go member

Snap gauge for measuring outside dimensions is the counter part of the pin gauge. It measures the part or diameter at one point only. This type of gauge is usually inexpensive whether it is a commercial type adjustable gauge or simply made from plate stock. Snap gauges can be divided into three types (*a*) plain adjustable snap gauges (*b*) plain solid snap gauges (*c*) thread roll snap gauges. The first two types have both go and No go dimensions incorporated on the same end. They may have the go member and No go member at two opposite ends. Wickman gauge is an important snap gauge in which both go and No go members are at the same end and both can be adjusted if worn out. A snap gauge may at times prove superior to a ring gauge at an inspection tool. A ring gaage ma accept out of round work pieces that would bs rejected by a sna gauge.

Flush Pin Gauges :

The Flush pin gauges Fig. 24.4 measures the relativc po of the bottom of the hole or the shoulder by meanr of a movin

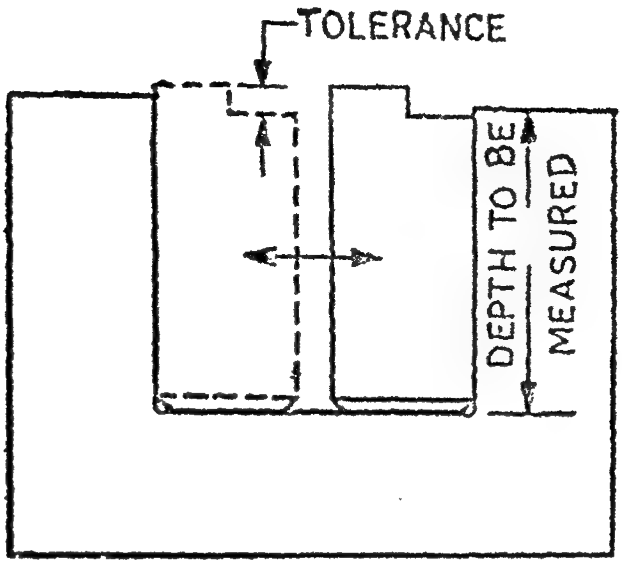


Fig. 24.04. A flush pin gauge

The limits are set by two ground surfaces and determination is made by passing the finger and over the edge of the pin. It is a relatively simple gauge to use and is more accurate than the plate gauge.

Plate gauges :

The plate gauge is the most common type of gauge for offset dimensions. It is also the most rapidly used gauge. It is not however likely to be as accurate as other gauges. Offset dimensions are those dimeneions which measure the distance from one point to another where the measuring pressure on both points is in the same direction. These include the depth of a hole. the distance to a shoulder in a shaft and the like.

Receiver gauges :

They are similar to ring gauges but are used to verify the specified uniformly of size and contour of non-circular holes. They are extensively used to check splined shafts.

Gauge materials :

Hardened alloy steel may be commonly used as gauge material for gauging members. However for mass production runs gauge wear surfaces of mild steel are often chromium plated also. When a high

degree of accuracy must be maintained, the production run is long and wear is excessive tungs-ten carbide contacts are often used to form gauge members. There is one advantage of chronic plated gauging members, when the points wear out they can be replaced. Cheap gauges can be made of mild steel and case hardened at the places which wear out.

General design considerations of limit gauges :

1. Gauges should be designed as light as possible without impairing the rigidity. As the gauges are to be used very frequently they should not be the source of fatigue to the worker.

2. The gauges should be built of a material which has been properly stabilised in dimensional change. They should not change dimensions due to the effect of prolonged ageing.

3. The gauges should be made wear resistont either by case hardening, or using a steel that can be hardened or they may be chromium plated.

4. Gauges designed for blind holes should be provided with relief air grooves permiting the escape of air and reducing the time to guage Fig. 24.5.

5. The gauges can be designed for low cost by building them up from wear resistant steel for mating portions and ordinary steel for handles etc.

6. Over all design of a guage should be such that minimum time is taken to position, engage or disengage a guage. A pilot provided at the nose of a plug gauge helps in speeding up the operations of positioning, engaging and disengaging.

PRINCIPLES OF GAUGE DESIGN

In the above pera the design consideration have been discussed only from Industrial Engineering point of view. Hewever the main

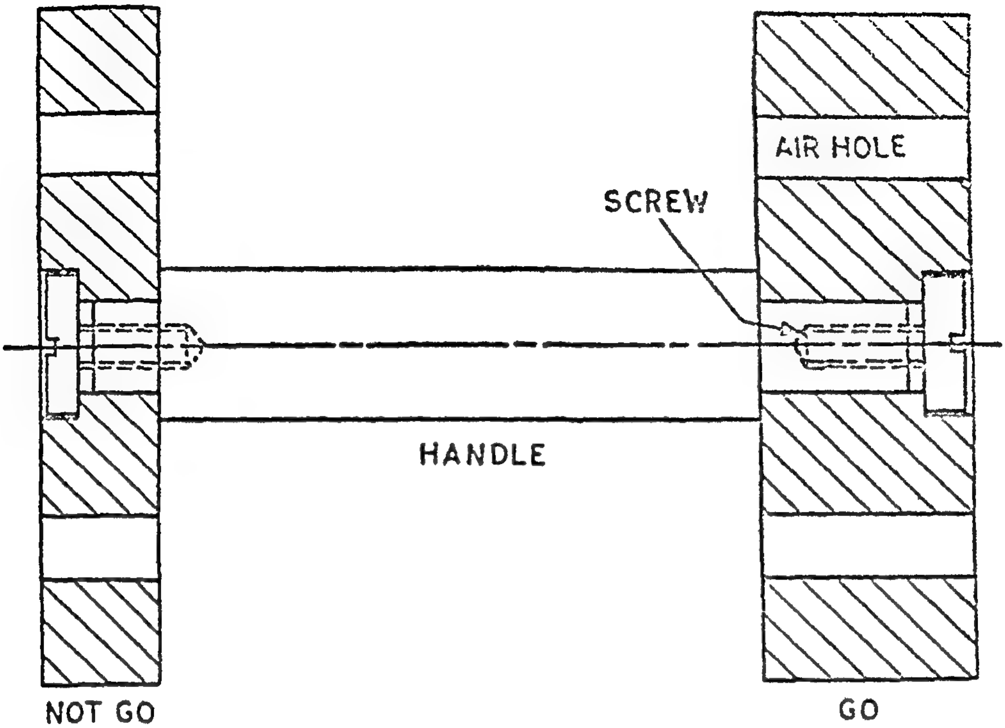


Fig. 24.05. A gauge for gauging in blind holes

function of a guage is to keep the size within tolerence. A gauge which must control the size between two limits H limit and L limit must consist of two parts go part and No go part. In engineering menufacture most of the shapes which are to be assembled are either hoies or shafts. They are assembled to give certain fit even though each component *i e.* the holc or the shaft is manufactured to a knowa tolerance. The gauges to control the holes are called plug gauges and gauges to control the shafts are called ring gauges and each further consists of two parts the go part and No go part. Before enunciating the rule to determine the size of go and no go part of either plug gauges or ring gauges, it is worth while to become familiar with two more terms (1) Maximum metal limit and (2) Minimum metal limit.

Maximum metal limit : It is the maximum (biggest) size limit of an external feature such as shaft and minimum (smallest) size limit of an internal feature *i.e.* Fig. 24.06.

Minimum metal limit : It is the minimum (smallest) size limit an external feature such as shaft and maximum (biggest) size limit an internal feature such as a hole. Fig. 24.6.

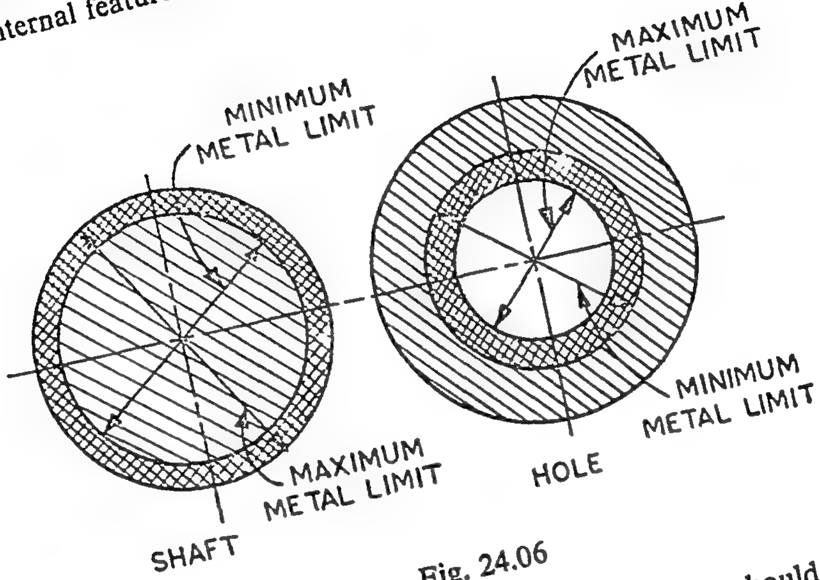


Fig. 24.06

Design rule No. 1 : The go gauge dimension should conform to the maximum metal limit and No gauge dimension shoul conform to the minimum metal limit of a feature whether exter or internal.

According to the above rule if a bearing block (hole) di sions are to be controlled at $1.500^{+.003''}_{-.060''}$ the high limit c size will be 1.533" and low limit of the size will be 1.500". Th gauge for this component will have the go size conforming maximum metal limit whico in case of an internal feature minimnm size limit. Hence go size will be 1.500". Agai size of gauge should conform to minimum metal limit which of an internal feature is the maximum size limit. The No thus be 1.503". The working of such a gouge is very sim

No go part also goes in the hole the dimension is bigger and if the go part does not enter, the hole is smaller in dimensions. Hence for this hole to be within $1{\cdot}500 \begin{smallmatrix} +{\cdot}003'' \\ -{\cdot}000'' \end{smallmatrix}$ the go part should enter and No go part should refuse to enter.

Again suppose shaft for this bearing is to be produced and controlled at $1{\cdot}500 \begin{smallmatrix} -{\cdot}001 \\ -{\cdot}004 \end{smallmatrix}$ the high limit of the size will be 1·499 and low limit of the size will be 1·496″. According to the design rule 1, the go dimension for a ring gauge to control the shaft dimensicas will agoin conform to maximum metal limit whica in case of an external feature is maximum size limit. Hence go size for a ring gauge will be 1.499. Again No go size will conform to minimum metal limit which in case of an external feature is minimum size limit. Hence No go size will be 1,496. If go size does not go over the the size of dimension is bigger. If no go size slides over the part the size of the dimension is less. For exact. For exact control go size should slide over and go size should not slide over the part.

Design rule No. 2. This rule is known as Taylors principle of limit gauging and is applicable where two or more dimensions having a fixed geometrical relation are to be controlled. The rule states that the go gauge should incorpoorate the maximum metal limit of as many pimensians as it is convenient and suitable to gauge in one operation but separate No go gauges should be used to check the minimum meral limit of each dimension in turn. To illustrate let there be a rectangular hole of size 1·500″ × 2·000″ which a tolerance in 0·020″ on each side. Figure 10·7 shows the shaded tolerance zone in which the sides of the hole must fall in order to comply with the requirements. If separate go gauges were to control the low limits of the sides of the rectangular hole it might have the shape indicated by the chain dotted line and still be accepted as satisfactory by these go gauges. The only satisfactory go gauge which adequately ensures that the shape of the whole nowswhere encroaches on its maximum metal limit is the go gauge shown figure 10·7 (*b*). It incorporates the low limits of both the tolerance dimensions of the component and is called a full form gauge.

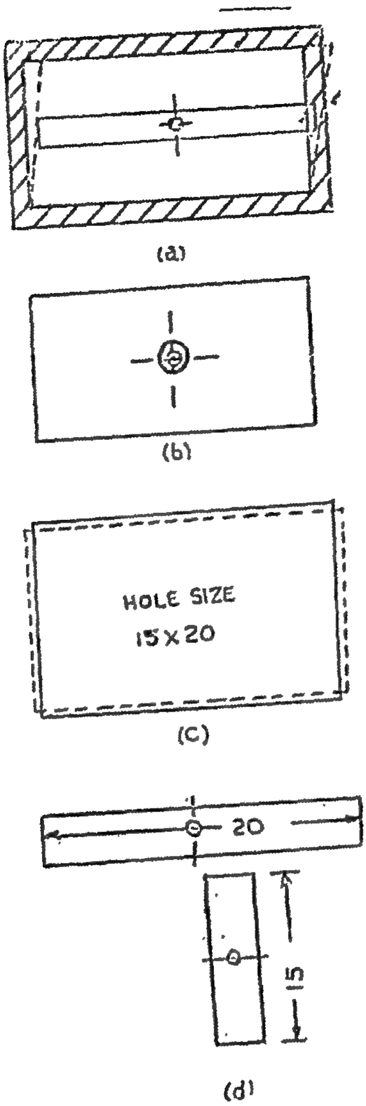


Fig. 24.7

If a No go gauge is desiged to control simultancously th minimum metal limit of more than one dimension, it might pass a satisfactory the components which are out side the minimum meta limits. One snch No gauge is shown in the figere. Correctl designed No go gauges must control the minimum metal limits of or dimension only.

Gauge tolerances

Parts are manufactured to a tolerance because it would require much time and skill to manufacture then to a particular dimension and gauges control these sizes within the tolerances. However even the gauges themselves can not be manufactured to their exact sizes. Here also not only time but great skill is required in an attempt to make or adjust contact surfaces of gauges to their exact size. Like the components, gauges are made or adjusted to be within a small per missible dimensional range known as gauge tolerance. Like work piece tolerances, gauge tolerances are also very necessary. Gauge tolerance is generally determined from the amount of workpiece tolerance. The 10 percent rule is in general use for determining the amount of gauge tolerance for fixed limit type working gauges. When no gauge tolerance is specified by the gauge designer 10% rule many be conveniently followed by the gauge maker. Working gauges are used by tne operators on the machines to control the dimensions. Howevei inspection department to check the shop production are provided a tolerance of 5% of work tolerance Tolerance on mater gauges which are used to check the accuracy of other gauges is 10% of the gauge tolerance.

Four classes of gauge makers tolerances have been established by American gauge design comm ttee. The degree of accuracy requir-ed determines the class gauge to be used. Table shows these tolerances for the four classes for certain nominal size steps.

Class XX gauges are precision lapped to the very closest tolerances practicable. They are primarily master gauges.

Class X gauges are also precision lapped to close tolerances. They are used as inspection gauges or sometimes for working gauges also.

Class Y gauges are precision lapped to slighly wider toler-ances than X gauges and can be used for inspection work or shop purposes.

Class Z gauges are precision lapped. They are working gauges with liberal tolerances.

Proceeding from class XX to class Z. tolerances become progressively greater. The cost of a gauge depends upon the tolerance desired. Closs tolerances add to tne cost of the gauge.

To illustrate the method of determing gauge tolerance take a 1·520 inch hole with a working tolerance of ·0016″. Then according to 10% rule the gauge tolerance on each member of working gauge will be ·00016″., According to standard gauge makers tolerances it will be a class Z gauge, Even if the work tolerance is more than ·0016″, the gauge tolerance should not exceed ·00016″ as provided in the table of standard tolerances, However if the working tolerance is smaller than ·0016″, say ·0012″ then gauge toleranc would be ·000012 and it will be a Y class gauge. The tolerance for inspection gauges for tnis component will be still close and will be ·00008″ for a class X gauge.

Standard Gauge Makers Tolerances

National size		Gauge makers tolerance classes			
Above	To and in-	XX	X	Y	Z
0.029	0.825	0.00002	0.00004	0.00007	0.00010
0.825	1.510	0.00003	0.00006	0.00009	0.00012
1.510	2.510	0.00004	0.00008	0.00012	0.00016
2.510	4.510	0.00005	0.00010	0.00015	0.00020
4.510	6.510	0.000065	0.00013	0.00019	0.00025
6.510	9.010	0.00008	0.00016	0.00024	0.00032
9.010	12.010	0.00010	0.00010	0.00030	0.00040

Allocation of Gauge tolcrances :

Having determined the tolerance for a specific gauge, the direction plus or minus of that allowance must be decided. Two

basic system unilateral system and bilateral system are in use to distribute these tolerances round the nominal size of each of the gauge member, Go and Not Go.

In the bilateral system, the Go and Not Go gauge tolerance zones are bisected by the high and low limits of the work piece tolerance zone. Fig. 10.8.

Let the dimension of a hole $=2.500 \text{ cm.}{}^{+.001 \text{ cm.}}_{-.001 \text{ cm.}}$

Work tolerance $=.002$ cm.

Hole size varies from 2.499 to 2.510

$$\text{Gauge tolerance} = \frac{.002 \times 10}{100} = .0000 \text{ cm.}$$

$$\text{Dimensions on Go plug gauge} = 2.499 \text{ cm.}{}^{+.0001}_{-.0001}$$

$$\text{Dimension on Not Go plug gauge} = 2.501 \text{ cm.}{}^{+.0001}_{-.0001}$$

Such a gauging system can reject parts which are within the working limits and also can can accept parts which are outside the limits. But the quantity of both kinds will be very small because if the process is under control a few percent of tne total production falls near the *H* aud *L* limits. Greater portion of the production is in the middle of normal curve.

Unilateral system :

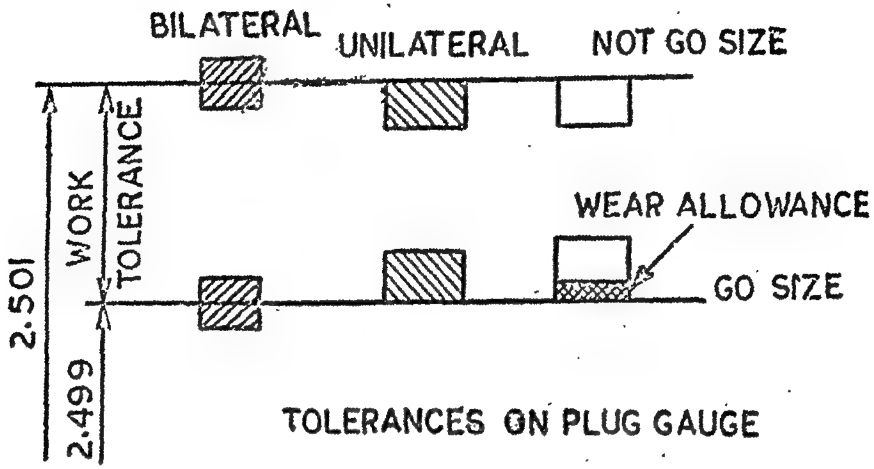
In this system, the work tolerance zone entirely encompasses the gauge tolerance zone. This makes the work tolerance zone smaller by the sum of the gauge tolerances but guarantees that every part passed by such a gauge regardless of the amounts of gauge size variation will be within the work tolerance zone. Fig. 24.08.

Taking the previous example of a $2.500 \; {}^{+.001 \text{ cm.}}_{-.001 \text{ hole}}$

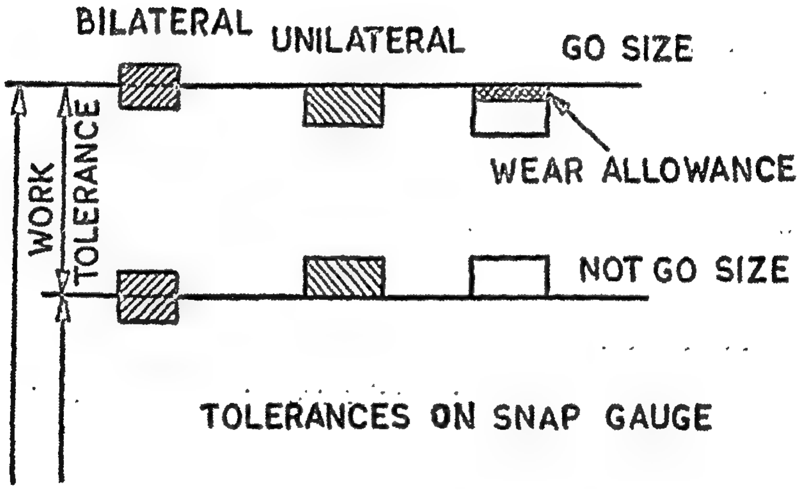
and using 10% as gauge tolerance

$$\text{Go gauge dimension} = 2.499 \; {}^{+.0002}_{-.0000}$$

$$\text{Not Go gauge dimensions} = 2.510 \; {}^{+0\ 0003}_{-0.0002}$$



TOLERANCES ON PLUG GAUGE



TOLERANCES ON SNAP GAUGE

Fig. 24·08

In this system of allocation of gauge tollerances, parts may be rejected as being outside the working limits ween they are not. In this respect it is like bilateral system. But it is different from bilatral system in the other respect *i.e.* all parts passed using unilateral system will be within the workicg limits.

Gauge wear Allownce :

Although the gauges are hardened and lapded to a fine finish they are subjected to wear. Go gauge wears out sooner because it

constantly rubs against the surface to be gauged. Such a gauge can wear beyond usefulness very soon unless some allownce for wear is built into the gauge at the start. The wear allownce is thus a dimensional increment added to the nominal diameter of a plug gauge and subtracted from that of a ring gauge. It is used up during the gauge life by wearing away of the gauge metal. Wear allownce is applied to the nominal gauge diameter before gauge tolerance is applied. This allownce must be kept as small as possible because, although the larger it is, the longer can the gauge wear without praducing scrap work, until the gauge has wron considerably, but the work will be produced to a smaller tolerance than necessary for correct functioning. The cost of producing such pieces will almost certainly be higher because of the replacement and resetting of the sizing tools. When the work tolerance is large such as .003 cm. it would be safe to assume .00015 cm. that is 5% of work tolerance for wear but for smaller tolerancces .0001 cm. must suffice. To avoid too large a wear allownce, the surface is made highly wear resistent by plating with hard chromium. By this means the gauge life is increased to two to four times. It has been estimated that standard slip gauge wear approximately .00001 cm. for every 1000 times they are wrung together.

The size of plug gauge after applying the wear allowance is obtained as follows in reperence to fig. 24·08.

For a $2.500^{+.001\text{ cm.}}_{-.001\text{ cm.}}$ hole, work tolerance = .002 cm.

Basic dimension of the Go plug gauge = 1.499

using 5% af the work tolerance as wear allowance

wear allowance = .0001 cm.

adding to this basic dimension,

Basic dimension of the go plug = 2.4991 cm. Using the unilateral system now :—

$$\text{Go plug gauge} = 2.44991^{+0.0002\text{ cm.}}_{-0.000}$$

$$\text{Not Go plug gauge} = 2.5010^{+0.000}_{-0.0002\text{ cm.}}$$

QUIZ

1. What is a limit gauge ?
2. How gauges are classified ?
3. Why plug type gauge is not used for checking bores of longer diameter ?
4. How does a flush pin gauge differ from a pin gauge ?
5. What are the four classes of gauge makers tolerances ?
6. Distinguish between Unilatcral and bilateral systems of tolerances.

CHAPTER 25

SURFACE FINISH AND ITS MEASUREMENT

Different machining operations generate surfaces of different characteristics. Surfaces generated by turning milling, shaping, planing, grinding and superfinishing show marked variations when compared with each other. The variation is judged by the degree of smoothness. A surface generated by superfinishing is the smoothest one while that by planing is the roughest surface. This kind of judgment is based on visual inspection and it fails to differentiate between surfaces produced by same machining operation but under different cutting conditions. A basis of quantitative evaluation is required in place of qualitative assessment. While defining the assembly of the two mating parts it becomes absolutely necessary to describe the surface finish in quantitative terms which is a measure of micro-irregularities of the surface and expressed in microns. Also for proper function or to prevent stress concentrations, it may be necessary to avoid or to have certain roughness profiles.

Machined surfaces are produced by combination of two motions—(*i*) relative longitudinal motion of the tool or job and (*ii*) transverse movement of the tool or job. The previous is due to inherent action of the production process and the later is due to feed marks.

25.01. Macro-Geometrical Deviations :

These are single deviations from the ideal geometrical form and extend over the whole surface being tested. Out of roundness, lack of flatness, taper form or barrel forms are examples of such deviations. They are created due to inaccuracies of slides and wear of guides over long use. These are characterised by the large ratio of length L_1 of the surface to its deviation h. from the proper form (Fig. 25.01) Ratio $\frac{L_1}{h}$ should not normally be greater than 1000. However, if this value is required to be less for proper functional requirement of the deviation should be specified in drawing.

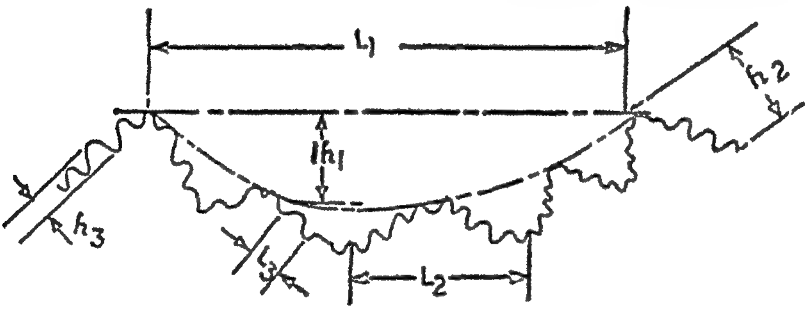


Fig. 25.01

25.02. Micro Geometrical Deviation (Surface Roughness)

These are also, a series of regularly repeated deviations of a wave with a ratio of pitch to height L_3/h_3 comparatively quite small and approximately 50. These deviations are produced by the trace of an edged cutting tool and plastic flow of the metal during machining. Usually, these are finer irregularities in the surface texture and is termed as surface roughness. To describe the surface roughness the height of the irregularities is measured and rated in microns and its width in mm.

Flaws :

Irregularities that occur at one place or at relatively frequent intervals on the surface such as a ridge, hole, peak, crack or check

are called flows. Unless or otherwise specified the flaws shall not be included in the roughness measurement.

Waviness :

Waviness is the usually widely spaced component of surface texture and it is normally of wider spacing than the roughness width cut off. Waviness may result from such factors as machine or work deflections, vibrations, chatter, heat treatment or warping strains.

Waviness Height :

It is rated in mm. as the peak to valley distance.

Waviness Width :

Waviness width is rated in mm. as the spacing of successive wave peaks or successive wave valleys.

The measurement of waviness is quite different from the average roughness, since maximum peak to valley and wave length dimensions are specified. Waviness is usually measured with dimensional gauges referenced to a master surface such as an optical flat.

Lay :

Lay is the predominant direction of the surface pattern. This is normally determined from the method a job is produced.

2.03 Effect of Surface Quality on Functional Properties :

The quality of the surface finish of running and sliding parts has a great deal to do with how long these items would last. It has a marked influence on the following functional properties of machined parts.

1. **Wear resistance :**—Larger macrogeometrical deviations cause non-uniform wear of different sections of a surface. Projecting areas of the surface are worn off first. Macrogeometrical deviation may occur where roughing cuts are applied to castings, due to unbalancing of inner stresses Therefore, such castings, may be

seasoned after the roughing cuts and are finish cut, when the changes have stabilized. Beds of machine tools are manufactured with great care to avoid macro-geometrical deviations. They are given roughing cuts, seasoned and finished afterwards.

In case of waviness the crests are worn down first. Same is true of ridges of micro-irregularities. As only the crests of mating surfaces are in contact the intensity of pressure over these places become high and hastens wear of such surfaces. Peaks of the irregularities break the lubricating film also and dry friction at those places adds to the wear.

However, some sort of roughness is desirable to absorb the lubricating film which cannot be retained in perfectly smooth surfaces. The optimum surface finish desirable can be established experimentally, for various conditions of friction (in accordance with the load, speed, lubrication, material of the bearing surfaces and other factors).

2. Fatigue Strength :

The valleys between ridges of a machined surface may become the focus for the concentration of internal stresses. These valleys between ridges behave like scratches and a crack may start from these scratches which are points of high stress concentration. Many such cracks lead to subsequent destruction of the machine part and part is said to have failed by fatigue caused by stress concentrations.

3. Strength of interference fits :

When a part is press fitted into another, the actual interference obtained in press fitting a part with a rough surface would differ

from that obtained from a smooth part (having the same measured diameter of the press fitted surface).

4. **Corrosion resistance :**

The resistance of machined surface against corrosive action of liquids and gases, water, air, acids in lubricant etc. is greatly influenced by the quality of finish. The deep valleys of a rough surface have a capacity to contain more corrosive substances which cause corrosion in the depth of metal. A highly finished surface has fewer valleys and corrosion in the depth of metal will be less.

23.04 Factors Affecting Surface Finish.

Quality of machined surface depends on many factors which can be listed as below—

(*i*) The material of workpiece.

(*ii*) Type of machining operation.

(*iii*) Rigidity of machine-work-tool system.

(*iv*) Type, form, material and sharpness of cutting tool.

(*v*) Cutting conditions.

(*vi*) Type of cutting fluid used.

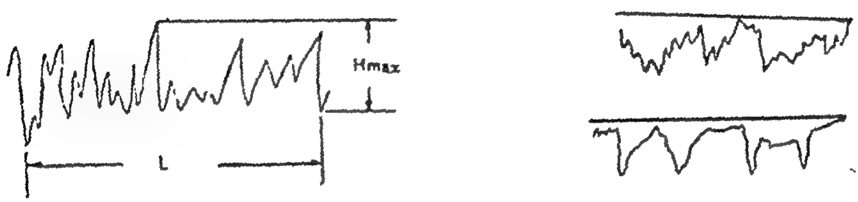
23.05 Evaluation of Surface Finish.

Many methods have been developed to express the surface finish of the surface numerically. These numerical values are obtained with respect to a datum. Two such datums have beer described a little afterwards. Some of the well-known methods for reading the values of surface profiles are gives below :—

(*a*) **Peak to Valley Height Method (Rautiefe)**

This method is largely used in Germany and Russia. It mea-

sures the total depth over a given sample length and largest value of the depth is accepted. Thus the instrument reads the value directly. The drawback with this method is that it may read the same H_{max} for two largely different texture fig. (25.02*b*). The internatioual symbol for this is R_a which means average roughness height.



(a) (b)

Fig. 25·02

(*b*) **Centre Line Average Method :**

CLA method, as it is most widely known, is an arithmetic average of the ordinates drawn about a centre line of the profile read over the sample length. If the ordinates are y_1, y_2, y_3 in microns then.

$$Ha = \frac{y_1 + y_2 + y_3 + \ldots\ldots y_n}{n}$$

$$\text{Also } Ha = \frac{1}{L} \int_{x=0}^{x=L} |Y|\, dx$$

Now a days direct reading instruments are also available. The method is very widely used in the world

(c) Root Mean Square Method :

RMS method, as it is commonly known, is geometrical average of the ordinates of the profile about the centreline (fig.). RMS value is not used so frequently as H_{max} and H_a. It can be expressed mathematically as

$$H_{rms}=\sqrt{\frac{y_1^2+y_2^2+y_3^2\ldots y_n^2}{n}}$$

$$\text{Also } H_{mas}=\left[\frac{1}{L}\int_{x=o}^{x=L} y^2dx\right]^{\frac{1}{2}}$$

It should be noted that for the same profile and sample length Hrms is upto 11% greater than Ha. The value 11% refers to a perfect cosine curve.

23.05 Systems of Datum :

Two systems have been defined to determine the datum of measurement for British and American methods are based upon *mean line* system (M-System), whereas Germany, France and Switzerland have adopted *envelop system* (E-System) for their measurement.

M-System :

A mean line has to be determined first for the surface profile. This line is defined as one which runs parallel to the surface and is so placed in the profile that areas above and below the line are theoretically equal. The centre line average values or root mean square values are based on this system.

E-System :

This system prescribes that average deviation from the envelope curve is the measure of roughness. This curve is obtained by rolling

rcle of radius R (which is 25 mm) across the surface fig (25.03). It uches the peaks of the surfaces and is parallel to the locus followed y the centre as it rolls over the surface.

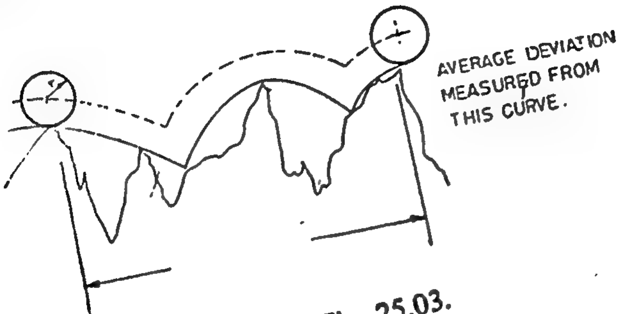


Fig. 25.03.

Analytical Evaluation of Surface Roughness.

(i) A Simple Case

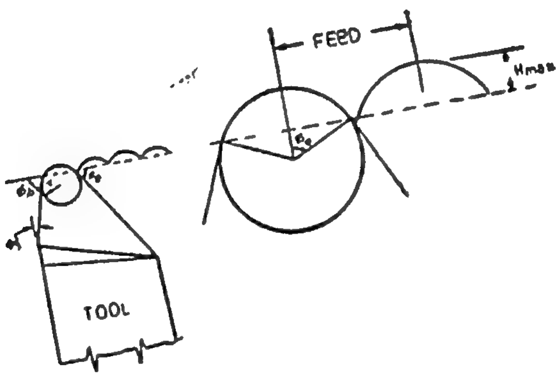


Fig. 25·04.

Let $\phi_p=\phi_e$, then

$$H_{max}=r-\sqrt{r^2-\left(\frac{f}{2}\right)^2}$$

$$\text{or } H_{max}-r=-\sqrt{r^2-\left(\frac{f}{2}\right)^2}$$

$$\text{or } H_{max}^2 - 2r\ H_{max} + r^2 = + r^2 - f^2/_4$$

$$\text{or } 2r\ H_{max} = \frac{f^2}{4}$$

$$\text{or } H_{max} = \frac{f^2}{8r}$$

$$\text{Provided } \sin \phi_c = \frac{f}{2r}$$

$$\text{or } \phi_o \geqslant \sin^{-1} \frac{f}{2r}$$

$$\text{or } \phi_s \leqslant \cos^{-1} \frac{f}{2r}$$

(*ii*) General expression is

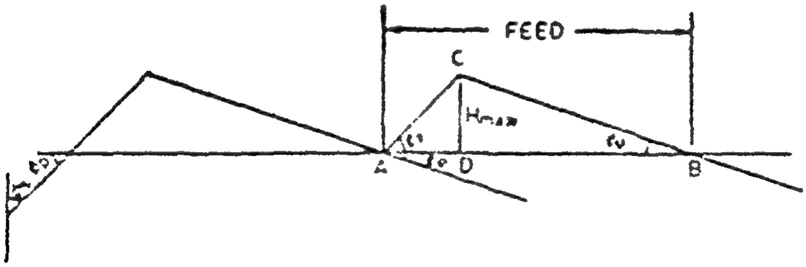


Fig. 25.05.

$$AB = (f) = AD + DB$$

$$CD = AD \tan \phi_p = DB \tan \phi e$$

$$\text{or } \frac{AB}{DB} = \frac{\tan \phi e}{\tan \phi_p}$$

or $f/DB=(\tan\phi_p+\tan\phi)e$

$$\therefore\ DB=\frac{f\tan\phi_b}{\tan\phi_p+\tan\phi e}$$

$$\therefore\ CD=\frac{f\tan\phi_p\tan\phi e}{\tan\phi_p+\tan\phi e}$$

$$\tan\phi_p\ H_{max}=\frac{f}{\text{Cot}\,\phi+\text{Cot}\phi_p}$$

Drafting symbols for surface roughness ;

The surface roughness according to ASA-*B* 461–1955 is represented on the drawing by a 60° check mark placed on the line indicating the surface. The roughness height in μ inches root mean sq. average, roughness width in thousands, direction of lay and waviness height in thousands are all shown in proper places. If roughness height is 63μ inch and ·0005" is width of roughness irregulairties and these irregularities are $\perp$ to the line indicating the surface they are shown as given :—

Roughness height$_{63}$ (μ) $\sqrt{\ }$ 0·002 (waviness ht (·001 mm) $\perp$ 0 005 (Roughness width (·001 mm)

thousands Symbols indicating direction of lay

$=$Parallel to the boundry line of the nominal suface indicated indicated by the symbol.

$\perp$Perpendicular to the boundary line of the nominal surface by the symbol.

X Angular in both directions to the boundry line of the norminal surface indicated by the symbol.

M Multidirectional.

C Approximately circular relative to the centre of the norminal surface indicated by the symbol.

R Approximately radial relative to the centre of the nominal surface indicated by the symbol.

Methods of measuring surface roughness :

1. **Visual Inspection :** The sense of feel by drawing a thumb-nail across the surface sometimes gives an idea about comparative roughness of two surfaces. To a highly skilled person it can give roughness value of the surface quality. To facilitates this kind of inspection a suitable microscope may be used.

2. **Surface Roughness Blocks :** These are a set of blocks made to know surface roughness numbers in rms μ inches, or arithmatic averages. These sets can be obtained in various forms, one standard set containing blocks having roughness values of 2, 8, 16, 32, 63, 125, 250 and 500 in rms. Roughness as produced by lapping, polishing, grinding, milling and shaping are usually represented. The surface whose roughness is to be found out is compared with these blocks by feeling with thumb nails. This method is also not exact but it is improvement over the first method and gives approximate value of roughness for setting other averaging instruments. Sometimes averaging instruments can be checked with the help of these blocks.

3. **Profile Records :** The detailed study of surface profiles can be made through inspection of profile records. Modern instruments for producing profile records are capable of including data from a large amount of surface in a reasonable space. Such instruments which produce profile records are called profile graphs. They operate on the following principle Fig. 25.05. The diamond stylus I, pivoted together with the mirror 2, passes over the machined surface. A

beam of light from a lamp passing through the precision slit and

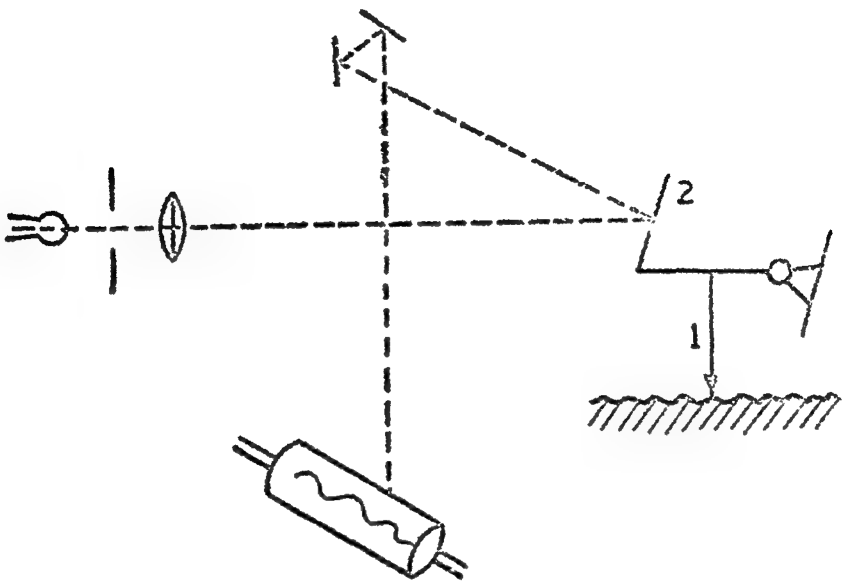


Fig. 25.06. Principle of obtaining a profile graph

lense, falls on the mirror. Upon oscillations of stylus 1 imposing over the tested surface, the direction of the light being reflected from mirror 2 is changed. This beam is directed through a system of mirrors to the revolving drum with light sensitised paper. A record of the light beam, reflected by the mirror remains on the paper. After developing, the light sensitised paper will show a graph of the microprofile of the inspected surface, magnified from 400 to 2000 times in the vertical direction and 10 to 50 times in the horizontal direction. Brush surface analyzer is an instrument that gives both a profile record and a meter reading in μ inches rms.

Owing to extremely irregular aspect of most practical profiles, it is difficult to place a general valuation on a surface from the inspection of the magnified profile curve. Only a trained inspector

can make consistant estimates of peak to valley heights from such records and these estimates may differ from inspector to inspector.

4. Averaging Instruments :

A number of electrical instruments are available that operate on the principle of a fine (0·0005 inch radius tip) stylus that is moved over the surface to be checked. Such instruments interpret the surface automatically and produce a reading in the form of a single number. They are called profilo meters. Commercial instruments of this type give the reading either in inches rms or arithmatic average according to the design. Brush surface analyzer, Surfindicator and Talysurf are commercial profilo meters is use. Surfindicator has a range of 0—1000μ inches and talysurf a range of 0—200μ inch rms. Brush surface analyzer moves back and forth over 1/16" length in 10 secs. These instruments do not give a total surface indication. Flaws, waviness or some scratches too minute to measure will not show up on the record. The principle of a profilo meter is as follows. The vertical movements of the tracer point are transmitted to a coil inside the tracer body. The coil moves in the field of a permanent magnet and this produces a small fluctuating voltage that is related to the height of the surface irregularities.

The tracer may be moved either manually on mechanically over the surface of the work. Mechanical movements give a more consistant and dependable roughness measurement. Surfaces measured may range from 1μ inch or less upto 1000μ inch of roughness. A roughness specimen is always provided with these instruments for checking the coagition of the tracer point.

5. **Optical surface meaning instruments :** An optical surface roughness measuring instrument such as the surface finish micro-interferometer makes use of light wave interference principles and provides a quantitative measurement. A similar instrument capable of measuring roughness depths between 1·2 and 400μ inch is the *interference microscope.* This instrument is *often referred to as* 45° microscope, or the light section microscope. The light is permitted *to shine through* a slit *falling on the work in the form of* a fine band Fig. 25·07. This band of light traces out the profile of

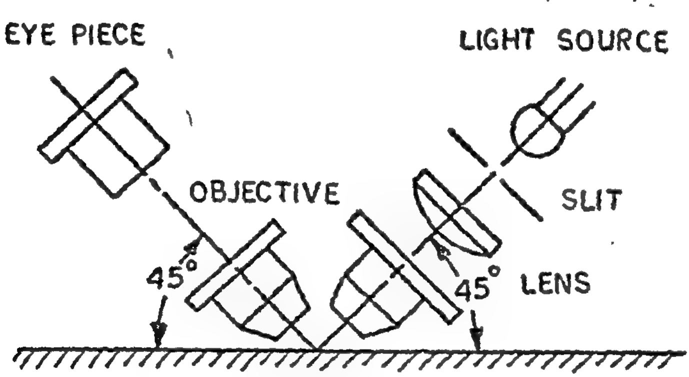


Fig. 25.07. Interferometer

the surface, that is its crests and valleys. A reticle in the microscope can be shifted within the field of view to measure the height (or width) of the surface irregularities. Both roughness and waviness may be determined.

Two advantages of using optical instuments in measuring surface roughness are that they do not mar the work and they can

be used to measure more than one parameter at a time. They also can measure surface roughness, waviness and flaws.

Surface roughness available by common production methods :

Machined and ground surfaces	Value of roughness in μ inch rms
Rough turning	63—2000
Rough milling	63—1000
Shaping	32—503
Rough grinding	32—250
Finish mill	16—250
Smooth turning	8—250
Broaching	8—125
Finish grinding	4—32
Internal honing	1—16
Polish	0·5—32
Super finish	0·5—16

Surface produced by other methods :

Sand casting	275—1000
Forging	100—500
Permanent mould castings	50—400
Die Casting	16—200
Rolled and cold drawn	10—200
Extruded	10—200
Phosphate coated	100—150

QUIZ

1. Distinguish between surface roughness and surface finish.
2. What is the nature of surface texture in the case of ideal turning ?
3. How is centre line average value smaller than the r.m.s. value ?
4. Describe the M-System and E-Systems of atum.
5. State the conditions for the relation max$=\dfrac{f^2}{8r}$
6. Describe the stylus method of measuring surface roughness.

CHAPTER 26

PROCESS PLANNING AND COST ESTIMATING

The product that awaits for final shipment at the factory gate to be sent to the consumers is the result of a great planning and control at many stages. The planning function takes many forms to complete the industrial activity of manufacturing a product. First and most comprehensive is the administrative planning which sets in motion, coordinates and controls the enterprise as a whole and creates the policies to guide those under the direction of the management. The management creates an organisation consisting of departments to carry out the policies laid above. Product planning is the next phase of planning and is carried by *Product Engineering* department of the organisation. The product as decided by the management after careful market surveys and sale forecast is designed by the *Products Designers* in consultation with others. Product Planning determines the final shape of the product after considering several designs and prepares assembly drawings, working drawings with complete specifications of the components of the product. It remains for the process planners now to do their job before actual manufacture starts. Main task of the process planning function is to ensure the output of the product which completely meets the stipulated specifications.

Aim of Process Planning :

Processing planning is a fundamental part of the industrial activity. An efficient and economic planning leads the firm towards

success where as faulty planning creates hinderances and bottlenecks at each stage of manufacturing. Process planning aims at planning method or a series of methods for the economic manufacturing of a product of the quality called for by the drawings or specifications laid down.

To achieve the main setforth process planning proceeds as follows :—

1. It determines what parts to be manufactured and what parts to be purchased from the market.

2. It determines the most economical processes to be followed to manufacture components of the product which are to be manufactured in the shops.

3. It determines the sequence of operations to be performed on each component in a particular process.

4. It determines the blank sizes of raw materials in processes like forging, welding, pressing and gross weights of materials for costing purposes.

5. It prepares a material list for all components of the product in preparation to purchasing the raw materials. (Table 1).

6. It determines the machine tools to do the operations at required accuracies and prepares complete specifications of such machine tools.

7. It determines the need of any special equipment like tools, jigs and fixtures and dies in the light of production quantities.

8. It determines the stages of inspection and also the need of designing the inspection devices and limit gauges for different stages of manufacturing.

9. It determines the time standards for performance of the job and fixes the rates of payments in piece payment system.

10. It determines the kind of labour required to do the job and may determine the estimated cost of the product even before the manufacturing starts.

Process planning is a dynamic process and is never complete even though the product is going out of the factory gate. Process planners keep them continuously busy in making the product more the more economical. They strive to reduce cost by searching for cheap materials and minimum use of materials. They try to reduce labour costs by simplifying operations with the help of tooling equipment. They are continuously analysing the product and its components from all angles. All this is possible if the process planning department is organised in scientific manner.

Organisation of the Process Planning Deptt.

Head of a process planning department is the Process Engineer who has become a specialist in the field by nature of his experience in the shops and in the tool design offices. He is a man of initiative and self-confidence and is never afraid to go to shops and talk to the workers. He should be able to borrow ideas and at the same time be able to sell his own ideas. Process Engineer is helped in doing his work by a team of specialists in their own branch of knowledge. Tool Engineer advises on the need of tooling equipment. Industrial

Bill of Materials Sheet

Date.......... Contract No.......... Sheet . .. .

Product.......... Sheet No ....

Sub-Assembly No.	Symbol or Part No.	Name of Part or Component	Material Name	Material Code No.	Specifications or chemical analysis	Size of Material	Weight		No-off per assembly	Total weight	
							Net	Gross		Net	Gross

engineer finds standard time of the operations listed in the operation sheets. Estimator estimates the final cost of the product. A typical organisation of a Planning department looks like this :—

- Process Engineer
  - Planning Engineer
    - Planner
    - Planner
    - Planner
  - Tool Engineer
    - Designer
    - Designer
    - Designer
  - Industrial Engineer
    - Methods Men
    - Time Study Men
  - Estimator
    - D/man
    - D/man

Process Planning Sheet

The whole information determined by the process planning function is recorded in a sheet in tabular form. This sheet is the result of all efforts by planners and is used for further action by other departments of the organisation. It is called by other names also like analysis sheet, instruction sheet, operation sheet or process design sheet. The form of this sheet may vary for different production conditions. The character of a sheet will depend mainly on the scale of production and the degree of importance of the product being manufactured. The degree of detail in planning manufacturing processes for the manufacture of aviation engine differs from that for rock crushers even if both are produced in small lots with the same total output. In the majority of cases, however the following datas are listed in the process sheet for each component of a product :

1. Information concerning the component, its name and drawing.

Process Planning Sheet

No. of Sheet .. ..
Sheet No... ....

Date ... ...
Drawn by ...

1. Product.........
2. Part name.........
3. Drawing No . ...
4. Symbol Code No.........

5. Material.........
6. Code No.........

7. Blank Size... .....
8. No. of parts per article ....
9. Annual requirements.........
10. Lot size.........

11. Net wt.........
12. Gross wt.........
13. Any other information.........

Sketch.........

1. No.	2. Operation Description	3. M/c Model	4. Shop	5. Standard tool	6. Jig Fixture	7. Gauges	8. Cutting speed	9. feed	10. RPM/Stroke/mnt	11. No. of passes	12. Depth of cut	13. M/c-ing time	14. Handling time	15. Set up time per lot	16. Cycle time	17. Job rating	18. Labour cost	19. Remarks

2. Information concerning the blank (character, material from which it is made, size of stock when used as a blank etc.).
3. Description of shops, operations in each shop and elements of operation in proper sequence and locating points for each operation.
4. Information concerning the kind of machine tools, auxiliary tools and other manufacturing equipment.
5. Data on jigs, fixtures and tools (their code numbers).
6. Inspection devices and limit gauges (their code numbers).
7. Cutting data.
8. Elements of standard time such as setting time, handling time and machining time.
9. Job rating of the worker for each operation.

A typical process planning sheet is shown in Table Selection of machine tools, the sequence of operations and inspection stages are determined mainly by the *Process Engineer* in consultation with process planners who are experts in their own field like casting, forging and press working. The columns on tooling equipment are filled in consultation with tool engineer. The copy of the process planning sheet is given to tool engineer to design the tools listed in the sheet. Similarly the Industrial Engineer with the help of his men fills the remaining columns on cutting data and standard time for each component.

Scope of Process Planning

Process planning function of an organisation prepares a vital information in the scope of process planning sheets for further action. They are used for further planning of the following :—

1. *Estimation* :

   To prepare cost estimate of the product for quotation purposes for fixing the cost of the product even before it is actually manufactured and cost sheets are still not available.
2. *Layout Planning* : To layout and design a complete factory for a new product or change the existing layout for a new product.

3. *Production Planning* : To plan production in a existing shops for a new product or component along with the other parallel products also running.

If the new product is to be manufactured in an old plant then process planning and production planning functions are the same. But when the plant is still not there and it is to be designed, the function is called process planning, only as different from production planning, In production planning the machines being already there, their availability and capability information should be with the planners. Process planning simply does not take into account such information. It determines the equipment either for purchase from outside or for guiding production planning.

Pre-requisites for Process Planning

Some of the information required for process planning is supplied by the *Product Engineering Section* alongwith the drawings and specifications of the product and its components. Some other kind of information is kept ready by the process planners for ready reference. Total information required or the pre-requisites can be listed as follows :—

1. Working drawings of non-standard components of the product alongwith the manufacturing specifications for the finished parts.
2. Assembly drawings showing the position of assemblies and sub assemblies.
3. Part list of all components of the product differentiating standard and non-standard parts.
4. Annual output of the product.
5. Number of components for each unit.
6. Accuracy and surface finish as provided in the specications of finished parts.
7. Material of each component and need for its treatment at various stages.

8. Equipment data *i.e.*, specifications and capacity data of the machine tools available from catalogues of various manufactures.
9. Data on cutting fluids used in industry.
10. Catalogues of cutting, measuring and auxiliary holding tools.
11. Standard of available stock sizes.
12. Data on metal cutting conditions, handling and set up times.
13. Tables of cutting tool approaches.

It is highly important to make a detailed and comprehensive study of the part drawing and specifications of each component of product before starting the process design. It should also be borne in mind where the part or component is to fit in the assembly. Prerequisite information that greatly influences planning is the tolerances and surface finish requirements and quantity to be produced.

Specifications on a detailed drawing

Specifications have been mentioned as a prerequisite for process planning. They are determined by the product planners and process planners have to design the process conforming strictly to those specifications.

Specifications specify the following :

1. Dimensions and machining accuracy of various surfaces, (limits).
2. Accuracy in the co-ordination of various surfaces (fits).
3. Places of heat treatment.
4. Surface finish, finish method.
5. Places of protective coating alongwith type and thickness of coating.
6. Locating place for measurement of dimensions on finished parts.
7. Special inspection procedures such as X-rays or hydraulic testing of pressure vessels etc.

Part List Sheet

Date...... .....
Product...........

Contract No ....

Sheets ....
Sheet No...........

Sr. No.	Sub-assembly	Name of Component	Part No, Code No. or Symbol	Drg. No.	No. reqd. per assembly	Remarks

Designing for Production :

All that is designed in the design office of *Product Engineering* section is to be analysed by process planners for manufacturing. Some times the designs which are difficult to produce and will be costly can be made cheaper with a little change in design without impairing the function of the component. Such suggestions have been given by the process planners and components have been sent back for changes in design. Now to avoid such back tracking the advice of the process planners is sought right at the time of designing the component. Process planners suggest changes right at the moment. Such a design which takes care of production difficulties right at the drawing table by associating and seeking advice of planners is called a '*Design for Production*'. Such a procedure is being increasingly followed for efficient process design and economical production. In the *Design for Production* procedure process engineer checks the producibility requirement of each component designed by the product designer in a certain systematic order so that no fault remains over looked. Productibility is judged in a consecutive order in the following manner :

Steps :

1. Does the analysed design creates production difficulties and can it be simplified without impairing the performance of the part ?

2. Will it prove more expedient to substitute a reinforced design, weldment or assembled unit for the part being analysed ? Of course this may involve a change in the materials specified for the part.

3. Can high production methods be applied in the manufacture of the analysed part and does its design limit the machining speeds and feeds ?

4. Use all surface finish symbols, necessary for production, given in the drawing and it is possible to make direct measurements of the given dimensions?

5. Will any production difficulties arise in maintaining the specified dimensional tolerances and surface finish?

6. Are the specified classes of fit really necessary for the operation of the part or for other reasons?

Determination of Blank.

Blank is the starting point for all the machining operation to manufacture a finished component. The blank may be obtained by processing raw materials by methods like casting, forging, welding and rolling etc. The material of the part and the volume of production determines the method of manufacturing the blank which is tentatively chosen on the basis of the field of application of each method, the size, form and weight of the part, the working life of forging and press working dies, permanent metal moulds or moulds for plastic parts and characteristics. The chosen method should be approved by the process planner. Certain revisions in the part drawing may be required to suit the method adopted for blank manufacture. The chosen blank determines the subsequent machining process. The accuracy of the blank which depends on its methods of manufacture and the specifications for the finished machine part determine the general outline of the machining process and its sub-divisions into roughings, semi-finishing and finishing operations.

If the blank is a casting, its net weight, and gross weight are calculated by the process planner for making entries in the process sheet. If it is a forging the section of rolled bar or billet, bloom or ingot and its length are determined again for estimate of material costs. Process planning actually starts with the blank selection.

The operation performed on the raw material in processing and fabricating shops like forging, casting and welding are not entered in the process sheet. The time to make the blank on those shops is determined by separate analysis. The operations and their correct sequence in the machine shop are dealt in great detail while process planning because lot of labour is expended in the machining process and forms a major part of the labour cost.

Planning the Operation Sequence :

No operation sequence should be accepted blindly. It should be subjected to occasional review to see if new or better methods can be developed for increased productivity and reduced costs. It must be remembered that there is always room for improvement. To establish operation sequence for a new product or new component for estimating or plant layout and design purpose, the process planner is a free man and can have operation sequences best suited to his liking. However, to plan for production planning in an existing plant is a difficult job as he has to suit the operation sequence according to the equipment available and also its present loading conditions. The equipment most suited may be over loaded or not available at all. Establishing of operation sequence in the second case is possible if the process engineer is provided with the following information :—

1. List of available machines.
2. List of available general purpose tooling.
3. Capability of equipment.
4. Machine Load charts.
5. Plant layout and
6. Standard data.

However there are certain fundamental principles which are

to be kept in mind for determining the most efficient sequence whether it is process planning for new layout and factory planning or it is to be fitted in the existing shops. These principles are :—

1. First operations in the sequence should be, in which the largest layer of metal is removed. Thick layer reveals casting defects if any in the very beginning and the casting may be rejected right there. The thick layer removal releases the work piece of internal stresses and eliminates the danger of warping in subsequent operations. Thick metal removal requires large cutting forces so some machines can be assigned for such roughing operations only.

2. Finishing operations should be performed at the end of the operation sequence to reduce danger of damaging finished surfaces.

3. Roughing and finishing operations should be performed on different machine tools so that accuracy of machines meant for finishing may not be spoiled by excessive forces in roughing.

4. Datum surfaces should be selected with great care. Of special importance is the correct selection of the first setting up datum. The selection influences all subsequent machining operations. A surface which is to remain unmachined should be selected as the first setting up datum surface for the first machining operation. In the subsequent operations only machined surfaces may serve as setting up datum. Datum surfaces should be of ample extent so that they are not displaced or deformed by cutting and clamping forces.

5. Inspection stages should be introduced after (*i*) roughing operations (*ii*) before operations which are to be performed in other departments (*iii*) before laborious and important operations (*iv*) after the last machining operation.

6. Surfaces whose machining will not greatly affect the rigidity of the work should be machined earlier in the sequence.

7. The sequence of marching operations should be co-ordinated with heat treating operations performed in the process of manufacture. Deformations of the work piece after heat treatment will require an increase in the machining allowances for subsequent operations as to correct the geometric form of the part, distorted in heat treatment, by machining.

Selection of machine tools :

Machine tools for performing the operations are selected by the pleasures with the help of collections of catalogues provided by manufacturers. However, if the physical plant is already available then both availability and capability charts greatly help in proper selection. A machine tool may be capable of doing it but it must be able to do the job at a certain speed and it must be available for the purpose. Thus the selection of machine tools is a complex task. It is difficult to formulate invariable and exact rules for selecting the machine tool for any case of machining. In any case, the following factors must be considered in selecting a machine tool for performing a definite operation.

1. Machine tool selected should be able to give required machining accuracy and surface finish.
2. It should be able to give required output.
3. Power of the machine tool should be sufficient for performing the machining operations.
4. The performance must be economical.
5. The machine tool should be easy and convenient for operation by the worker.

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4. The performance must be economical.
5. The machine tool should be easy and convenient for operation by the worker.

A production capacity that ensure the required output for the given programme is one of the decisive factors in the selection of a machine tool for a definite operation. However, general purpose machines though of lower production capacity are more versatile than high production machines. They can be equipped for wide range of operations. So selection of a machine tool is to strike a balance between two extremes. As the quantity to be produced increases special purpose machines are preferable as they reduce the manufacturing costs sharply. For small quantities general purpose machines may be economical. Economic analysis is second important factor for selection of machine tools.

Capability Charts

Capability of new machine tools is known from the catalogues but when the product is to be fitted in the running shop the capability chart must be produced for reference. Machine tools do not remain in the same condition as purchased, they go on loosing accuracy due to wear etc. so the present conditions of the plant are shown by the capability chart. It may be necessary to finish machine a part to close tolerances due to the functional or end use of the part. In such cases, the number of machines that can be selected may be reduced to a few, due to the type or capability of the equipment required for these operations. The capability limits of critical equipment may be determined by making an analysis usually in the form of quality control charts, from which records may be made to guide the process planner in making his choice of the proper machines.

Availability Charts

Availability charts are also necessary when process planning is being done to fit a new product into an existing line. This chart is an itemised list of machines by classes such as engine lathes, turret

lathes, automatics and the like, giving the characteristics of each machine, feeds and speeds available, its model number, size, tooling available, general condition, identification No. and location. Cutting data columns can be filled alongwith the selection of machine tool if they are available on the availability charts. Cutting speeds and feed columns are filled for new machine tools with the help of catalogues of detailed feeds and speeds are mentioned.

Machine load Charts

Machine load chart in any particular week are prepared by production control organisation in advance. If the process planning is for immediate production then machine load charts should be available to the planner for selection of idle machines or utilising spare capacity of machine tools. Process planning is not so much worried about loading as production planning is. It is the production planners who have to introduce the plan for execution in the plant. Production planners may assign machine tools according to load charts once the characteristic of the machine tool has been mentioned in the process planning sheets.

Time Standards

The standard time per piece consists of machining time, handling time, setting time distributed over pieces to be manufactured in one setting and time allowed for various allowances Only the machining time. out of all the times can be calculated from the data entered in the columns of the process sheet. Other times are calculated by a specialist called, *Industrial Engineer* through the help of standard data, predetermined time system or actual time studies. *Industrial Engineers* make detailed study of the time for various needs and evolve a standard time for the piece because the labour

rate is also set up on the basis of time per piece. Therefore time columns of the process sheet are filled by *Industrial Engineers* to complete the work of process planning. Standard times evolved are used by production control office to develop load charts, by process planners to develop machinery requirements and manpower requirements.

Method of finding machining time and other times necessary to estimate the cost of the product will be discussed separately under estimating.

Processing Procedure.

Having discussed various topics of the process planning function it will not be out of place here to give a definite procedure to be followed for completing the process sheet for successful planning. This step by step procedure is as follows :—

Step 1 :

Properly identify the process sheet for future reference. Write the part name, drawing number, material, size of pieces and data etc.

Step 2 :

List the operations in proper sequence. Do not forget to mention inspection stages, heat treatment or tests if performed within operations.

Step 3 :

Assign the machines to the operations and also the department where these machines are located or will be located.

Step 4 :

Use tools like flow process chart, operation process chart along with stock layouts to evolve an economical operation sequence.

Step 5 :

Indicate the need for gauges, jigs, tools and dies in the appropriate columns for each operation or operation preferably with the help of a sketch to guide the tool engineer.

Step 6 :

Enter the feeds, speeds and travels in the forms and calculate machining time. Calculate handling times, set up times and other times from the standard data supplied by the *Industrial Engineering* section or let them do this job.

Step 7 :

Enter the standard time calculated and supplied by the other section. Indicate the rate of labour to be employed for the operation

Step 8 :

Send copies to *Industrial Engineering Section* for computing standard time and to Tool Engineering Section to start designing of tools.

Step 9 :

Enter the information received back *i.e.* Standard times and tool equipment numbers at proper columns.

Step 10 :

Send the completed process planning sheet to production control organisation or to estimators for finding the cost of product per piece.

Step 11 :

If the process planning is for a factory planning, use the information further for calculating number of machine tools of each type, their layout etc. for factory planning purposes.

Numbering of Tools :

The need of designing a special tool, jig or fixture is decided by the process planner and the tool is indicated by a number in the appropriate column of the process sheet. The order to design and manufacture this tool is given under the tool code assigned to it in the process planning sheet. When the manufacture is complete the code is marked on it so that the tool may be available from tool store whenever required, easily. The importance in identifying each required tool cannot be over-emphasized. It saves a lot of labour in order to find out the exact tool when the production is to be started.

Tool codes area combination of letters and or numbers used to identify with reference to its applications. There are numerous systems used in industry. Each system adopted serves the specific need of the company.

Example :

16	AW	40001
Code to define type of tool such as : Arbor 4 Drill jig 5 Lathe fixture 6	Customer of the component for which tool is needed.	Assign a part no next to a number already assigned under the tool code 16.

A separate page is maintained for tools under each tool code number. Assign a number to a newly designed tool.

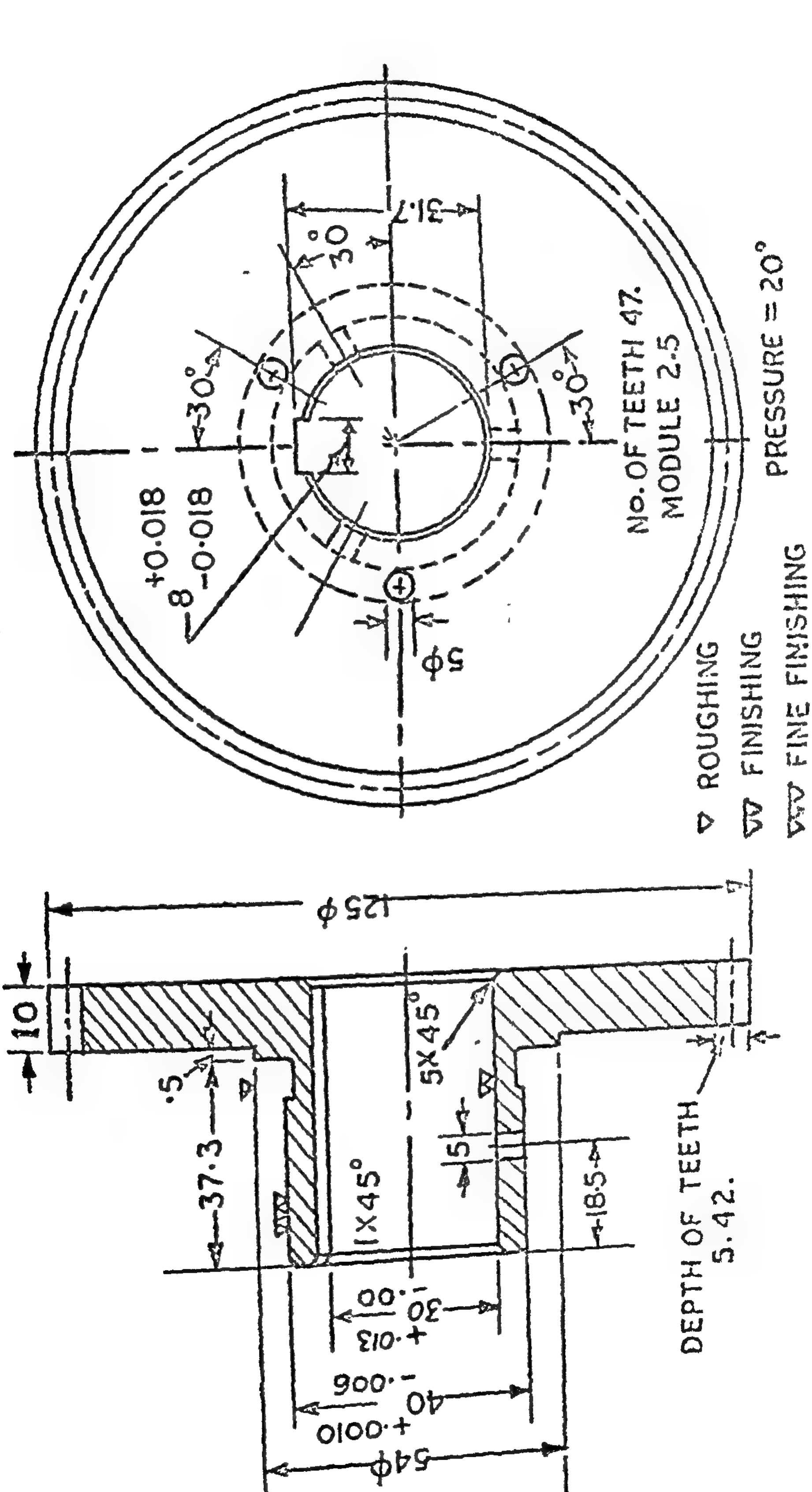

Fig. 26.1. Spur gear

A Simplified Operation Sheet

(For Fig. 26.01)

Sheet No...............

Total Sheets...............

Product..................
Part Name : *spur gear*
Drg. No...............
Symbol Code No........

Meterial........ ..m.s.
Code No...........
No. to be produced =10

Blank size 50×133 round......
Net wt.
Gross wt.................
Sketch...................

No.	Sequence of operations	Machines	Dept.	Jigs, Tools & Gauges	Remark
1.	Get a 130 ϕ m.s. round and cut to a length of 53 mm.	Power saw	Preparatory Section		
2.	Hold in three jaw chuck. Face front side about 2 m.m. Turn rough to 127 m.m. Remove job.	Turret Lathe	Machine Shop	Turning and facing tools Three jaw chuck.	Micrometer for checking 127 ϕ.
3.	Hold in three jaw chuck from other ride. Rough face 2 m.m. Turn to 42 ϕ a length of 39 mm. leaving a flange of about 12 m.m. length. Core drill 2·8 ϕ throughout from turret.	Turret Lathe	Machine Shop	Tool for turning and facing. Micrometer. Drile 28 ϕ along with socket to fit hole in hexagonal turret.	
4.	Inspect the rough dimensions, job still in three jaw chuck.	,, ,,	,, ,,	Micrometer, Scale & depth gauge.	

5.	Hold job from 43 ϕ and face one mm more and turn to 125 ϕ.	Turret Lathe	Machine Shop	Facing and turning tools, facing tool on square tool post.
6.	Hold the job against the body of the chuck as before on 125 ϕ. Face 125 ϕ keeping the thickness 10 m m. up to 54 ϕ. Face further keeping the thickness 10.5 m.m.+grinding allowance to 40 m.m ϕ.			
	Turn finish to 400,020 ϕ and give an under cut at the end 0.3 m.m. deep by 4 m.m. long.			Turning tool Micrometer
	Face finish such that depth from the face is 37.3+grinding allowance from 10.5 thickness flange.			Facing tool, depth gauge.
	Chamfer $0.5 \times 45°$.]			Chamfer tool
	Index turret, bring boring bar with bit fixed into it in position. Adjust and bore to 29 m m. internal dia keeping grinding allowance.			Boring bar, boring bit and internal micrometer.
	Chamfer edges of the bore. Remove job.			Facing rool used for internal chamfering.

6*a*.	Inspect finish dimension before gear cutting.		Inspection Deptt.	Dial gauges, depth gauges.
7.	Cut gear teeth in a hobbing machine keeping a grinding allowance.	Gear hobbing machine	Machine Shop	Hobbing cutter of required dimensions $Z=2.5$.
8.	Remove the cut blank and remove burrs.			Hand file
9.	Broach one key way length 47.8 and dia 31.7 mm.	Broaching machine	Machine Shop	Broaching tool Broaching fixture
10.	Remove the blank from broach fixtu re and remove burrs with file.			Hand file
11.	Hold job in a fixture so that both 5 ϕ holes of lengths 4.5 m.m. and 10.5 mm are drilled. Remove job.		Drilling machine	5 m.m. ϕ daill and socket.
12.	Case harden to depth of 0.5 m.m. and Rc 58 to 60.		Heat treatment Section	Heating furnace. Case hardening compounds.
13.	Clean the case hardened gear blank by sand.	Sand blasting m/c	Cleaning Section	
13*a*.	Check hardness.	Rockwell C machine	Testing Section	Testing kit.

14.	Hold the job in a cylidericaI grinding machine from gear teeth side. Grind bore to be $30^{+.013}_{-.000}$ Face 54, dia such that thickness is 10.5 and again face 40.02 dia such that depth is 37.3.	Cylinderical grinding machine	Grinding Section	Micrometer Depth Gauge	
15.	Set the machine for external grinding and grind the outer cylinderical surface to $40^{+0.010}_{-0.006}$ m.m. ϕ. Remove job for checking.	Cylinderical grinding machine	Grinding Section		
16.	Hold job in a suitable fixture of a gear grinding machine and grind gear to exact dimensions.	Gear grinding machine	Gear Section		
17.	Check gear tooth for shape, size etc.	gear test apparatus	Inspection	Gear testing kit	Final inspection of gear is carried out in inspection deptt.

Cost Estimation :

Next to process planning, cost estimation can also be prepared only by men fully experienced and trained in the profession. Such men must have worked in the industry before coming to the office for doing the job of an estimator. Cost estimates need to be most accurate as many decisions are taken on the basis of cost estimates only. These cost estimates may be required for such diverse purposes as :—

1. To predict the cost to manufacture a product, component, or a piece of jig, tool or die etc.
2. To control the cost of a product or component by analysing the constituents of cost.
3. To compare cost estimates of various methods or processes of doing a job and find out the most economical method.
4. To compare the cost of production over two machine tools or tooling set ups and decide about the machine tools or tooling set up to be purchased or replaced.

Estimation is thus the technique of predicting the essential manufacturing cost of a product or a single component of it or tooling set up with a reasonable degree of accuracy and within a minimum period of time by detailed analysis of the product, or its components. Estimation is different from costing or cost accounting in a big way. Costing concerns itself with the accummulation of facts pertaining to expenses of the enterprise such as material labour, over heads which are changable for a particular period of operation to a given department, to a specific product or component. Work of cost accounting progresses with the progress of the product through the plant. Cost procedure is long and complicated. Cost accounting section can tell the management about the cost when all activities are complete and the product is ready for shipment. Therefore the estimation technique is resorted to, to estimate the cost, for referring- to sales office enquiry or for even deciding whether to manufacture the product or not. Estimation can compare the cost of production of a product with one already in the market and decision regarding

starting the mnufacture can be made by management on the basis of estimates only. All commitments of todays competitive business as regards securing of contracts of profit desired out of a product are based on accurate estimations. Cost accounting is accomplished by commerce people and estimation by experienced engineers only. They are chosen out of the factory and given extra special training also.

Organisation for Estimation :

An enterprise which is catering to the needs of other firms and secures the contract be sending quotations must have an independent estimation department, because further orders are secured by accurate estimates only. However in bigger firms producing on mass production basis, estimation work is handled by process planners organised sepa rately for estimating of costs only. The place of such an estimater has been shown in the process planning organisation already. Big firms continuously estimate the costs of components, processes and methods or operations and also the tool and equipment for finding out the most economical alternatives In fact in a big organisation the work of estimation starts from the actual planning, which is done by process planners. Next phase of calculation of standard time is performed by industrial engineers, and the estimators do the remaining job of computing the costs by collecting the constituents of cost from various sources. However in an independent estimation department of a small organisation the estimator has to plan first, then he does the work of industrial engineer and finally complete the various constituents of cost. Here estimation will be discussed as an independent function which starts from drawing stage without knowing who performs it, whether it is the process planner or the industrial engineer.

Pre-requisites for Estimating :

Estimating proceeds from detailed drawings of the components of a product and these detailed drawings are fully specified planning stage of estimating require the same prerequisites mentioned for process planning as this part is actually an exercise in process planning. For computing stage the estimator should be equipped with.

1. Data on cost of materials and rates of labour or piece rates.
2. Catalogues about the cost of machine tools.
3. Rates of depreciation of the machinery and plant.
4. Indirect cost of factory, administration and selling.
5. Percentage indirect cost as percentage of direct labour or prime cost to be charged as constituents of cost.

Again the estimates are greatly affected by the quantity of production, as the setting time gose on being shared by more units in a lot.

Estimation for a Product :

A product like an automobile consists of hundred of components which are to be process planned first, then each operation, on a component may require the designing of a pattern, tool gauge, die for mass production running. Therefore, apart from the meterial and labour costs of manufacturing, the cost of manufacture of these tooling equipment must be found out separately as an independent estimate and shown as an item of direct expense for each component of the product. Similarly the cost of assembling a product should be estimated separately to be charged in labour costs.

Cost of Tooling Equipment :

Cost of tooling equipment needs to be estimated for adding as a direct expense item of each component. It may be needed to compare costs of tooling equpiment only. The procedure for estimation of the cost of tooling equipment is the same as for the product except that the work is of small nature and the designing and drafting of the tooling equipment forms an extra item. Tooling equipment may be listed as patterns, cores, jigs, fixtures, dies, tools and gauges. A tooling equipment item like jig or fixture or die will consists of the following costs items based on functions :

1. **Auxiliary services :**

   (*a*) Designing and drafting.

   (*b*) Production planning and drafting.

   (*c*) Procurement or fabrication of special patterns, core boxes, flasks or tools.

   (*d*) Experimentation, development, testing or runoff.

2. **Fabrication functions :**

   (*a*) Casting, forming, machining or finishing processes.

   (*b*) Assembly.

   (*c*) Painting, packing.

3. Direct meterials.

4. Direct expense as for painting etc.

5. Overheads.

Cost of set up tooling of equipment :

Sometimes the economics of tooling equipment is desired to be prepared for justifying the introduction of such equipment. Then in addition to cost of equipment, its setting up costs are also needed

for calculation purposes. Again two tooling set ups are compared in cost not upto cost of tooling equipment but upto the setting up stage.

The cost procedure for finding out the cost of tooling equipment is already discussed. The set up costs are found from the labour cost for the set up. Set up time is a column of the process planning sheet. The method of finding set up times will be discussed subsequently.

Constituents of cost :

Whether it is a big product, or a component or a tooling equipment all cost items can be conveniently grouped into three main constituents *i.e.*,

1. Material costs.
2. Labour costs
3. On costs.

If the designing or drafting has also been prepared in the case of a tool then charges on this item are also classified into material, labour or on costs.

Material costs :

Materials are further classified as direct materials and indirect materials. Direct materials come into the plant as raw materials and are processed in the plant and finally form the final finished part or component of the product. All other materials are indirect meterials and form a part of the on cost or burden.

Labour costs :

Labour engaged in a factory is also of two types. The persons who actually process the raw materials either on the machines or

manually in fitting and assembling shop form the direct labour. All other labour including foremen, supervisors come under the heading of indirect labour.

Expense or On cost :

All costs excluding direct materials and direct labour that may be incurred in transforming raw materials to finished shapes and selling them to society fall under this category. Indirect material and indirect labour also are items of expense. However, expense is also of two types : Direct expense and Indirect expense. All expenses incurred to manufacture a pattern, tool, core box, jig, fixture or forging die are the direct expense of a component. So excluding direct expenses all the indirect expenses fall into three categories. Therefore, reviewing the constituents of costs they will be :

1. Direct materials
2. Direct labour
3. Direct expense
4. Indirect expense $\left\{\begin{array}{l}\text{Factory expense}\\ \text{Administrative expense}\\ \text{Selling expense.}\end{array}\right.$

Factory expense items are the (1) indirect materials like shop supplies, lubricating oils, cutting fluids, fuel, oil, cotton waste, coal, gas, etc. (2) indirect labour like salaries of workshop staff, and drawing office staff and production clerks etc. (3) miscellaneous expenses are the taxes, insurance, maintenance, depreciation, power, light, stationery etc. Administrative expense includes such items as general office salaries, telephone, telegraph charges, depreciation of office equipment, office stationery etc.

Selling expenses are salaries of salesmen, commission to salesmen, advertising, cost of catalogues, price lists, salaries of clerks etc.

In the above direct material cost of a component, direct labour cost and direct expense can be found out most accurately by the estimating procedure to be described. However, the indirect expense items which are so numerous are determined by cost accounting section only, department-wise, which furnishes the figures to the estimator. The percentage these bear to the direct costs or total labour costs of a particular deptt. is calculated by them for finding out rate of overheads. The rate of overhead may change from department to department because an assembly or fitting shop with little equipment should not have to carry as heavy a burden as a machining department having heavy and costly machinery. Consequently direct costs for making an article may be kept separate for the various departments in which work is done so that the different overhead rates may be assigned to their direct costs. There are several methods of finding out rates of burden which are not dealt here and may be seen elsewhere. However, the overhead rate as percentage of direct costs is quite common in estimation.

Components of Cost :

Cost can be classified into four classes each representing certain items of cost :

1. Prime cost or direct cost. It is the sum of direct material cost, direct labour cost and direct expense only.
2. Factory cost or works cost : It is prime cost plus factory expense.
3. Manufacturing cost or cost of production : It is factory cost plus administrative expense.
4. Total Cost : Manufacturing cost+selling and distributive expense is the total cost of a product or component.

In case of a product which is thrown into the maket ,total cost plus profits desired determine the selling price. However in case of tools if estimate is required as an item of direct expense or simply for comparison with other tooling equipment, cost of production is the total cost also, because no selling overheads are to be charged.

Thus cost estimate of a product is direct material costs+direct labour+direct expense+total overheads. Direct material costs, direct labour and direct expense are to be determined by the estimation procedure. Each item of direct expense is treated like a separate product and similar procedure is followed for finding estimate of direct expense. Overhead in each case is added as percentage of direct costs according to a value already calculated for each department.

Esstimating Procedure :

1. Prepare a part list of all components sub-assembly wise and indicate each item by a code number.

2. Determine what to make and what to buy. Clearly mark standard items because they are certainly to be bought.

3. Start making the process planning sheet or simply an operation sheet listing the operations in proper [illegible] shop wise.

4. Indicate the machine tools selected [illegible] the machine tool is located [illegible]

5. Indicate the need of jigs, [illegible] priate columns.

The work so far may [illegible] section, if not, estimater has [illegible]

6. Prepare the bill of materials for all components whether manufactured or purchased. Also, find total cost of materials or total procurement costs in case of purchased parts separately.

7. Determine cutting speeds, feeds and travels from available data and from the component drawing and indicate in the columns provided.

8. Find out machining times for all operations. (Separate calculations).

9. Find out handling times by separate analysis of the operations. (Separate calculations).

10. Find out the set up times including tear down times and various allowances by detailed analysis separately. (Separate calculations).

11. Find the standard time, labour rate and labour cost also. Indicate in appropriate columns of the operation sheet.

    The process planning sheet is also complete now.

12. Determine the cost of direct expense *i.e.* any tool or auxillary equipment separately.

13. Determine the prime cost of the product.

14. Ascertain rate of overheads as percentage of prime cost or simply as percentage of labour cost. Find out overheads, department wise and total them.

15. Find out the total cost and handover the estimate to sale office or higher management.

In the above procedure the aim is to find material costs and labour costs for whole lot to be manufactured once. Rest of the

steps are preparatory to that. Both materials cost and labour costs are entered in the manufacturing estimate sheet for computation. Material costs and labour costs are prepared separately. Labour costs involve quite a detailed analysis of operations and elements to evolve standard time. They will be discussed now.

Estimate of Material Costs :

An estimate of material cost must include not only the material found in the finished article but also that consumed in scrap, waste and spoilage. Excess material is lost in chips, spoiled pieces, droppings, short ends etc. Casting net weight is found out from finished drawing but gross net weight for metal preparation is estimated for materials costs. Similarly the forging heat losses are taken into account for gross weight of a forging. Scrap loss is added to blank size in pressings. Methods of finding gross weight for filling appropriate columns are discussed in books. Hence bill of materials showing the gross weight or blank sizes of rolled sections, are prepared carefully. Many materials are priced by weights, so cost is found out from gross weights. In case of bar stock gross weight is found out by consulting tables of weight per unit of length.

In the case of bar stock to be machined an addition must be made to the length of the finished piece for the stock consumed by the cut off and facing tools. The length due to facing is taken about 2 mm where as cut off length depends upon the dia. of blank and width of cut off tool.

Estimate of Labour Cost :

Total time multiplied by the rate per hour gives the total labour cost. In piece rate system worker is paid according to pieces manufactured. But piece rate is again set by taking into considera-

tion the time per piece and the need to give fair reward to the worker. Time to do a job or operation consists of four separate parts

1. Set up times and tearing down times,
2. Handling times,
3. Machining times,
4. Allowances.

The operations along with their sequences are already written in the process planning or operation sheet. Each operation is now further analysed into elements. Each operation of turning, drilling or milling is accomplished by performing certain motions or movements. Sometimes the person is performing these motions while other times machine is busy while man is standing idle. These movements on the part of either machine or man or combined are called elements of operations. An operation thus requires four types of elements. Some are repeated for each cycle in which operation is complete others once for a lot. These elements are :

Set up elements

Handling elements

Machining elements

and Tear down elements

Set up times :

The set up times consist of the time of set up elements *i.e.*, the elements which are necessary to prepare the machine for the operation. They are the elements which occur only once for the whole lot to be manufactured and are not repeated in each cycle. Time to study the blue print, time to install the necessary tools in the

machine, time to make adjustments for getting the required size, inspection of the size of first piece are all set up elements. Hence the set up elements to do the setting are written down and carefully analysed. The time for each such element is taken from standard data tables available with the estimators for computing. Times for some important set up elements have been given.

Tear down times :

Tear down elements start when the last component of the lot has been operated upon. These are elements required for clearing the machine off the tooling equipment or auxilliary equipment. They also occur only once in a lot.

Handling times :

Once the set up is complete the operation is performed by the worker with the help of the machine in each component. Handling elements consists of all physical movements by the operator and are necessary to prepare the part for the machining element and disposing of the part when machining is complete. Handling elements repeat for each cycle *i.e*, each component. Like set up and tearing elements, standard data is available for these also. Some of these times are given at the end of the chapter.

Machining times :

Machining elements are performed by the machine only. A machining element starts when the tools touch the work and ends only when the tools leave the work. Actually there is only one machining element for each operation. Machining element times are calculated with the help of machining time formulae for each operation. They take into consideration the feeds, speeds, depth of cuts and tool travels. Sum of handling times and machining times is called the run time or Unit Operation time

Allowance :

The various allowances are :

1. **Personal allowances :**— (5 per cent) for the workers personal needs, such as time to go to the washroom, time for personal cleanliness, smoking etc. This time is reflected in the cost of the product and must be calculated.

2. **Fatigue :**—Excessive use of mind or muscles produce a feeling of tiredness decreasing the capacity to do work. Many factors contribute to fatigue such as long working hours, domestic problems, monotony of the job etc. Fatigue allowance varies from 5 to 25% depending upon working conditions such as

Automatic operations with short handling times and long cutting times	5%
Short cycle work, close tolerances, more of handling time or hand feed work	20%
Hand work under adverse conditions such as coldness, heat, dust, prolonged physical exertion	25%

3. **Cutter change allowance or tool resharpening allowances :**— Estimator should make some allowance both for tool changes or tool resharpening. The time needed to change a tool or resharpening it varies considerably from machine to machine.

4. **Inspection :**—It is necessary to inspect parts occasionally and readjust the tool to compensate for the wear. There may be several other reasons for the part to change dimensions. Checking the part regularly maintains the quality and detects tool setting movements. Frequency of checking actually depends upon the closeness of tolerances. Checking time in minutes for certain instru-

ments to check one dimension is

Outside Micrometer	0.15	minutes
Inside Micrometer	0.30	,,
Depth Micrometer	0.20	,,
Dial Micrometer	0.30	,,
Vernier Caliper	0.50	,,
Thread Micrometer	0.25	,,
Plug gauge	0.20	,,
Snap gauge	0.10	,,

Calculation of machining times :

All machining times can be calculated with the basic formula

$$T_m = \frac{L}{F}$$

Where T_m is the time to machine in minutes.

L is length of cut in inches or mms.

F is feed of tool in inches or mms per minute.

The length of cut L is the distance by which the tool or work piece is fed in order to cut away material plus approach of the tool plus over travel of the tool. The length of cut is called the total travel also. It is not always practicable to bring a tool precisely to the edge of the surface that it is to cut, nor always to stop it exactly at the other end. The small addition to the travel occasioned by these situations constitutes the over travel. The length of over travel in case of face milling and slab milling or slotting is calculated but in other cases like drilling or turning it is taken between 1—5 mm.

Approach is travel of the tool or cutter before it engages the work piece so that the tool may not strike suddenly when the automatic is applied.

Feed per minute is the distance tool advances on the job in one minute. Feed per minute is dependent upon depth of cut, fineness of the cut and rpm of the work.

$F = f \times \text{rpm}$.

Where f is the feed per revolution of the work or cutter and rpms are revolutions per minute of the work or cutter. Feed per revolution tables are available from feed data of the machine tool.

$\text{rpm} = \dfrac{12\,S}{\pi\,D}$ Where S is cutting speed in feet per minute of work or cutter and D is diameter in inches of work or cutter.

$= \dfrac{100\,S}{\pi D}$ Where S is cutting speed in meters/minute and D is diameter in centimeters of work or cutter.

Cutting speed is dependent upon the work to be machined and cutting tool material. Cutting speed also is obtained from tables provided.

Hence finally the time to machine in case of turning, milling and drilling is

$$T_m = \frac{L}{f \times \text{rpm}}$$

Where L is the length of total travel.

f is feed per revolution of the cutter or tool in case of drilling, milling and turning.

rpm is revolutions per minute of work in case of turning and cutter in case of drilling and milling.

Calculations for times of knurling, chamfering, and boring is similar to turning however the feeds are different. Similarly ream-

ing operation also uses different feed than drilling. Feed and speed tables for various operations are given at the end.

$$\textit{Time to cut threads} = \frac{\text{Length of cut (total travel)} \times \text{no. of cuts}}{\text{feed per rev} \times \text{rpm}}$$

$$= \frac{L \times N}{\text{pitch of threads} \times \text{rpm}}$$

because pitch of threads=feed per rev.

and N= No. of cuts=64×pitch for external threads (approx.)

=80×pitch for internal threads (approx.)

Length of cut is about 1/4″ greater than length of the work peace.

$$\textit{Tapping time} = \frac{\text{(Total travel)}}{\text{pitch} \times \text{rpm}} \times \frac{3}{2}$$

Where it is assumed that speed on return is twice the speed of advance. Total travel is length of thread length desired+length equal to tap diameter.

Shaping, planning and slotting time=time to sweep the area.

$$= \frac{\text{Area to be swept}}{N \times F \times S}$$

$$= \frac{L \times B}{N \times F \times S} = \frac{L \times B}{E \times F}$$

$$= \frac{L \times B}{K.C.}$$

Because E, the effective speed is equal to $N \times S$

and $E = K \times C$ where K is a factor and C is the cutting speed. Effective speed is only K times the actual cutting speed. Value of K is about ·75 of C. Units of each, must be taken care of before applying the formula.

Hence in the formula$=\frac{L\times B}{K.C.F}$ L is total travel in length

B is total travel in breadth

C is cutting speed

F is feed per stroke

and K is a factor about .75 in value.

N=No. of strokes mnt.

S=Length of stroke.

Cylindrical grinding operation times per pass$=\frac{L}{\text{feed per rev}\times\text{rpm}}$

$$=\frac{L}{\frac{w}{2}\times\text{rpm}}$$ $\because$ feed/rev of work$=\frac{w}{2}$ in case of roughing and w is width of the wheel.

$$=\frac{L}{\frac{w}{4}\times\text{rpm}}$$ in case of finishing.

feed$=\frac{1}{4}$ of width of the wheel.

Number of passes is based on depth of cut per pass which is 0.0001. to .004″ for roughing and 0.0002 to .002″ for finishing.

Broaching time in minute$=\frac{L}{\text{cutting speed}}+\frac{L}{\text{return speed}}$

Broaching feed is constant, equal to 0.08 mm or less between teeth. So the cutting time is dependent upon speed with which the tool is pushed or pulled through the work for the length of the broaching tool. Broaching speed are about 20-30 feet per minute for steel and return speed is twice the cutting speed.

Punch Press times. Punch press times are based on strokes per minute of the press. However during a day of eight hours in addition to time consumed by press action, time is needed for loading, unloading, locating and so on. It has been estimated that a press is working 24 minutes out of an hour with hand feed and 48 minutes with roll feed. Hence time to blank in minutes.

$$= \frac{\text{Number of blanks}}{\frac{24}{60}\text{ number of strokes per minute}}$$

$$= \frac{\text{Number of blanks}}{.4 \times \text{number of strokes per minutes for hand feed}}$$

$$= \frac{\text{Number of blanks}}{.8 \times \text{number of strokes per minutes for roll feed}}$$

Sawing times :

$$\text{Time to saw by power} = \frac{\text{Thickness to be sawed}}{\text{Work strokes per minute} \times \text{depth of cut of stroke.}}$$

Depth of cut can be varied from .15 mm to .08 mm as the dia or length to be cut increases. Number of strokes are about 70 for steel and 140 for brass or copper.

Production Estimate Sheet :

The material cost as obtained from bill of materials in the form of material cost sheet, labour cost obtained from adding set up times per component, handling time and machining times for each component in the form of operation sheet are entered in a tabular form in the estimate sheet. Prime cost is obtained to charge burden also. So prime cost+overheads of all components gives the total cost of the product. A production estimate sheet can be tabulated as follows :

Production Estimate Sheets

Customer

Date.............................

Total sheets ....

Product

Contract No............

Sheet No............

1. Sr. No.	2 Symbol or Code	3 Component	4 Material Cost	5 Labour Cost	6 Direct Expense	7 Prime Cost	8 Rate of over head	9 Burden	10 Total Cost

Grand Total......................

Set up Element times :

Engine Lathe Elements	*Minutes*
1. Going to Tool Store to bring necessary tools, gauges etc.	6·000
2. Install 3-4 Jaw chuck or face plate on the spindle	
(*a*) By hand	2·000
(*b*) By jib crane or hoist	5·000
(*c*) By crane	7·000
3. Install a live centre or dead centre	0·500
4. Install a tool holder in tool post	0·300
5. Install turning tool bit in tool holder and adjust for proper cutting angle	1.500
6. Set up and adjust compound rest and tool to cut tapers	2·000
7. Install drill or reamer in tail stock	·500
Drilling Machine Elements :	
1. Placing jig or fixture on the machine and adjust	
(*a*) Light	1 500
(*b*) Medium	4·000
(*c*) Heavy	10·000
2. Clean table or bed plate	·800
3. Install drill in spindle	1·500
4. Deliver part to inspection booth	·700
Tear down elements :	
1. Remove chuck, or face plate from spindle	
By hand	1·000
By Jig crane or hoist	4·000
By overhead crane	6·000
2. Remove collet chuck from spindle	0·300
3. Remove cutting tools from holders or tool holders	0 250
4. Remove live centre from spindle	0·300

5.	Remove dead centre from tail stock	0·300
6.	Return compound rest from taper to normal position	0·400
7.	Disengage taper attachment	1·500
8.	Blow the carriage clean or blow the fixture	·400
9.	Gather small nuts and bolts etc.	·250
10.	Remove jig or fixture from table	1·500

Handling Element times :

1.	Pick up part and install in chuck or between centres, or remove part and deliver to totepan	
	(*a*) bar and tube stock	0.500
	(*b*) casting and forging etc.	0·750 to 2·500
2.	Alignment with the help of dial indicator.	1·000
3.	Move cross slide into position, set tool to proper depth of cut, advance tool to work, engage feed.	0·200 to 0·300
4.	For tapering, release compound rest, swing to proper angle and secure	0·500
5.	For tail stock operation, clean the tool, release tail stock from ways, position tail stock with drill etc.	0 150
6.	Lock the tail stock in position.	0·250
7.	Tool resharpening, remove the tool, move the grinder, grind and return to the machine.	5·000
8.	Advance drill to work.	0·030
9.	Raise drill into clear.	0·020
10.	Remove part.	0·050

Cutting speeds for Turning, Boring and Milling using High Speed Steel Tool

1 Material	2 Ft/min	4 M/min.
Aluminium	1000	305
Brass (Commercial yellow)	250	76
Brass (Naval)	150	45
Brass (hard)	75	225
Cast iron (soft)	100	33
Cast iron (medium)	75	25
Cast iron (hard)	50	15
Copper	100	30
Magnesium	1500	450
Malleable iron	100	30
Monel (bar)	50	15
Monel (cast)	30	10
Plastics	1500	450
Stainless Steel	50	15
Steel Castings	75	22
Steel (low carbon)	100	30
Steel (high carbon)	50	15

Cutting speeds for Drilling using H.S.S. Drills

Material	Speed Ft/mnt.	Speed M/mnt
Aluminium	300	90
Brass	200-500	60-150
Phospher Bronze	50-125	15-37
Inconel	30-45	9-12
Cast Iron	75-110	22-33
Stainless Steel	30-40	9-12
Carbon Steel	70-90	21-227

Milling Machine feed per tooth

Material	Al.	Copper	Inconel	Steel mild	Steel medium	Tool Steel	Stainless Steel	Naval brass
Feed per tooth in inches	.005-0.025	.005.015	.003-.006	.004-.010	.004-.010	.001-0.003	.003-0.005	300.001
Feed per tooth in mm	.12-.60	.12-.37	.07-.15	.10-.25	.10.-.25	.25-.07	.07-.12	.07-.250

Plain high speed milling cutter, teeth and dia relationship

Dia of cutter in inches	2	$2\frac{1}{4}$	$2\frac{1}{2}$	$2\frac{1}{4}$	3	$3\frac{1}{2}$	4	$4\frac{1}{2}$
No. of teeth	8	8	8	8	8	9	9	10

Feed in Drilling in inches

Drill Dia	Less than 1/8"	1/8 to 1/4	1/4 to 1/2	1/2 to 1	larger than 1"
Feed in inches/rev	.001-.002	.001-004	.004-007	.007-015	.015-.025

Feed table n Millimeters

Drill Dia	Less than 3 mm	3-4	6-12	12-25	larger than 25 mm
Feed in mm/rev	.02-.05	.05-.10	0.10-0.17	0.17-0.33	0.38-0.64

Planer, Shaper and Slotter speeds and feeds

Material	Surface speed		Feed per stroke	
	Ft/mnt	M/mint	Inches	mms.
Al.	200	60	0.030-0.050	.70-1.25
Brass	150	45	.050-0.060	1.25-1.30
Steel & C.I.	100	30	.050-0.060	1.25-1.30
Alloy steel	50	15	.030-0.050	:70-1.25
Stainless steel	35	10	0.030-0.050	.70-1-25

Broaching speeds

Material	Al.	Copper	Inconel	Brass C.I. Bronze	Hard C.I. steel medium	Steel free machining	Steel hard	Mg
Cutting Speed Ft/mnt	50	15	10	40	20	30	10	60
Cutting Speed M/mnt	15	5		12	6	9	3	18

Turning feeds for depth of dut, varying from ·01 to 2·0 mm

Feed in mm/revolution of work

Dia of bar or work piece in mm	Vary	Fine	Medium	Coarse
Up 25	0.0254-0.0762	.1016-.2032	.2286-.3810	0.4064-0.8120
25 to 50	.0254-0.1016	.1270-.2540	.2794-.5080	0.5334-1.1436
Over 50 to 75	.0254-0.1270	.1524-.3048	.3302-.6350	0.6604-1.5700
Over 75 to 100	0.0254-.1524	.1778-.3556	.4064-.8890	0.9144-2.3622
Over 100	0.0254-.1778	.2032-.4064	.5334-1.1439	1.1430-3.1750

Tapping speeds using lubricants and H S S. taps

Material	Al.	Brass Soft	Brass Hard	Cast iron	Inconel	M. Steel	Steel Cast	Tool Steel
Tapping speed in M/min.	30	27	18	22-25	3-5	20-25	10	1

Reaming with H.S.S. reamers

Feeds varying from .004″ to .010 and stock allowance of 1/64″

Material	Al.	Stainless Steel	Brass	C.I.	M.S.	Tool Steel	Malleable Iron	Inconel	Mg.
Reaming speed in F/min	250	30	150	70	75	30-40	60	10	400

Bxample .

1. Estimate labour cost of manufacturing two hundred mild steel bushes shown in figure if the whole lot is to be produced in one setting over a turret lathe. Operation is paid at Rs. 076 per hour.

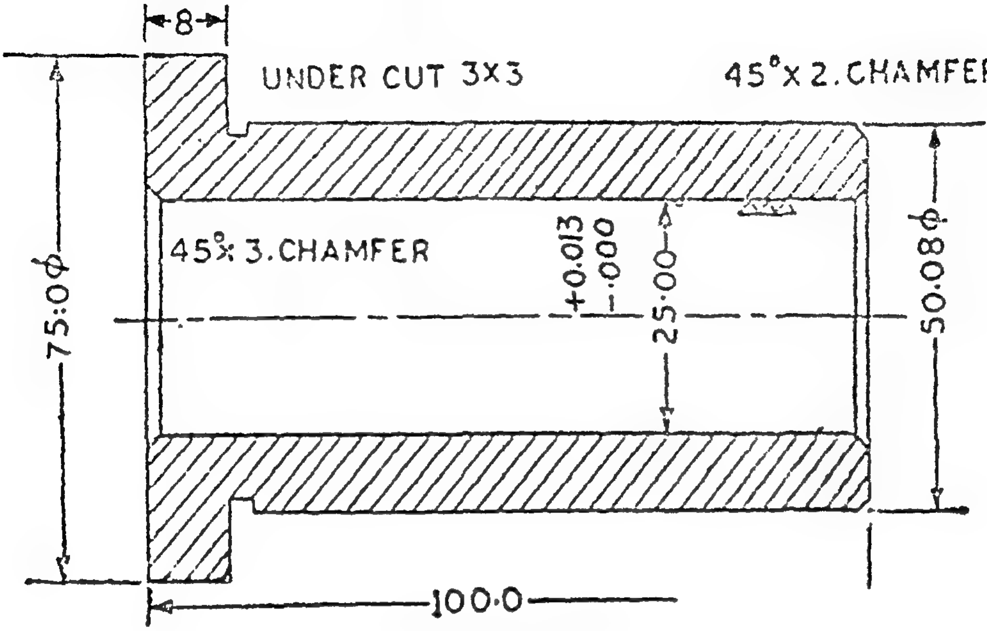

Fig. 6.2

Fig 26 2

OPERATION SHEAT

Name of Part : Bush Material M.S. Quantity in one Lot—200, Quantity per setting=0 Machine Turret

1	2	3	4	5	6	7	8	9	10	11
Sr. No.	Detail of operation element	Tools	Cutting	DIA	RPM	Feed mm/mnt	Actual Cutting Time in mnts	Handling Time	Set up Time in mnts	Remarks
1.	Bring the tools from stores	...	...	...	...	...	...	...	600.mnt	Once for 200 lot.
2.	Fix tools in hexagonal turret and square pott	...	...	...	...	...	...	...	6.00mnt	Once for 200 lot.
3.	Install 3 jaw chuck	...	...	...	...	...	...	...	2.00mnt	Once for 200 lot.
4.	Install a 76.2 mm ϕ bar stock in 3 jaw chuck	...	...	...	...	...	...	...	$1.50 \times 20 = 30$	20 times for 200 lot total 30 mnts.
5.	Bring cross slide in position for facing	...	...	...	...	...	...	.200	...	
6.	Facing operation length 38.1	facing tool	30 M/mnt	76.2	100	150	2.55	...	...	

1	2	3	4	5	6	7	8	9	10	11
7.	Back cross slide and tool from work	...	...	...	...	...	..	.300		
8.	Bring centre drills on turret in position and advance to work.	...	...	...	..	..	...	.500		
9.	Centre drill length 6 mm	Centre drill	30 M/ mnt	1/40	1500	.05	.08			
10.	Back turret slide, index turret and bring turning head into position	...	...	...	...	...	...	.500		
11.	Set the turning tool for 50·8 ϕ and drill for 16 mm	...	...	...	...	...	...	...	2·0	
12a	Turn 50·8 ϕ length 92 mm	Turning tool &	30M/ mnt	76	100	.20	4.60	—	—	
12b	Drill 16 mm length 120 mm	Drill	30 M/ mnt	15	640	·20	1.90	...	...	
13.	Stop spindle, bring turret back and index	...	...	...	...	...	...	·100		
14.	Inspect dimensions	...	...	...	...	...	...	.500	...	
15.	Increase bore to 24 mm ϕ 120 long	Drill	30	34	400	.40	75	—	...	

1	2	3	4	5	6	7	8	9	10	11
16.	Bring cross slide into position, index and bring necking tool in position Check 92 ϕ mm length	...	...	...	...	...	.300	...	...	
17.	Face and produce necking length 12 mm	Necking tool	30	76	100	.150	.87	...	...	
18.	Inspection again	...	...	...	...	...	...	.200	...	
19.	Bring the 24 mm. ϕ drill back, index and bring second turning head in position.	...	...	...	...	...	...	.330	2.00	
20.	Adjust to 75·0 ϕ	...	...	...	...	...	...	...		
21.	Turn 75.0 dia head, length 8 mm	Turning head	30	76	100	.40	·20	...	...	
22.	Bring the turret back, index and bring slide tool in position	...	...	...	...	...	...	.300	..	
23.	Set the boring bit in boring bar for 25.000 ϕ	...	...	...	...	...	...	...	...	
24.	Internal boring length 110	Boring bit	30	25	400	.150	1.80	...	...	

1	2	3	4	5	6	7	8	9	10	11
25.	Inspect boring with a plug gauge	Plug gauge	...	...	...	...	...	.200	...	
26.	Bring the turret back and index double to bring stop in position	...	...	...	...	...	..	.200	...	
27.	Move cross slide into position and index sq. post to bring champering tool into position	...	...	...	...	...	...	.200	...	
28.	Champering internal and external edge one by one		...	...	...	.	...	.200	...	
29.	Back cross slide and move 100 mm. Index sq tool post to bring parting tool in position	... ...	...	...	...	...	...	.300	...	
30.	Parting operation length 25 mm	Parting Tool	30	7.5	100	2.50	...	...	...	
31.	Open three jaw chuck Advance stock against stop Index stop	...	...	...	...	...	.003	.003	...	
							15.25	4.700	50.00	

Operation time $= 15.25 + 4{\cdot}700 = 19.95$ mnts

Time per piece $= 19{\cdot}95 + \dfrac{50.09}{200} = 20.20$ mnts.

Time fcr 200 $= 67.3$ hours.

Labour cost 50.47 Rs.

QUIZ

1. Prepare a process planning sheet for a m.s. headed jig bush for 1/2″ dia (12 m.m) hole. The bush is chamfered at 45° at proper places and is given an under cut of 2×2 mm at the neck. Other dimensions are head dia 25 m.m Outside dia 19 m.m. Thickness of head 6 m.m. Overall length 25 mm. Estimate the machining time of one bush.
2. Prepare a simplified operation sheet for a guide bush component shown assuming the component is available for mass production. Estimate operation time including handling and set up time. Fig. 26.3

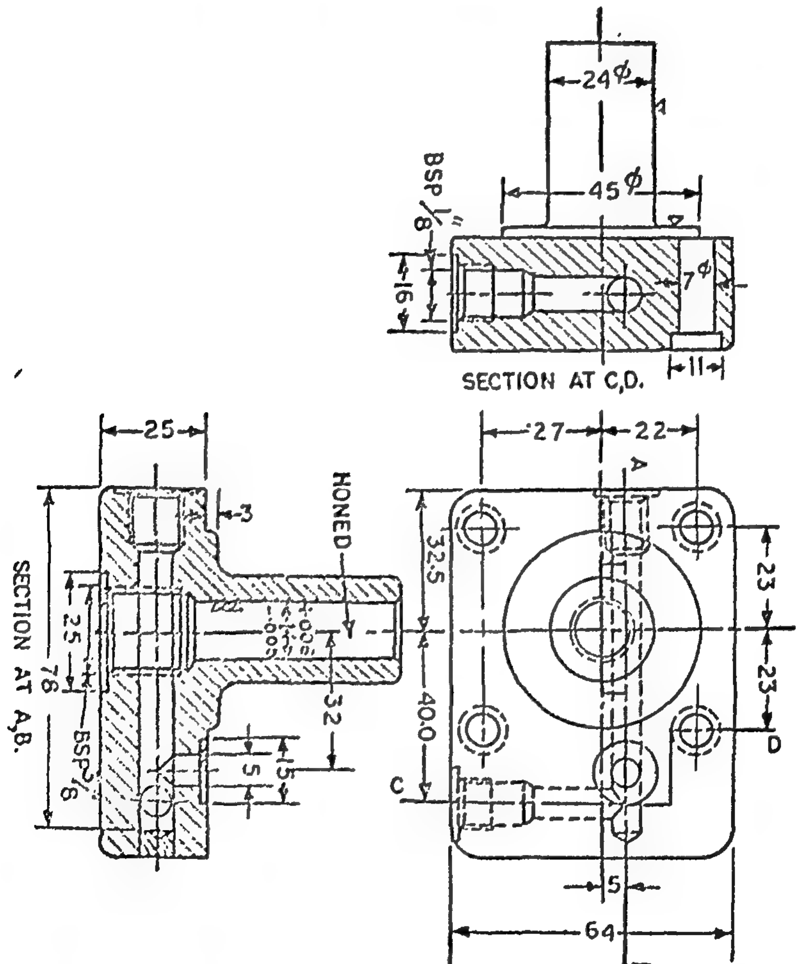

Fig. 26.3

3. Prepare a simplified process planning sheet for a double gear blank to be prepared on mass scale from rolled stock forging. Find the total cost of manufacturing the piece excluding material cost if 100 such pieces are manufactured. Assume the gear blanks are available. Fig. 26.4.

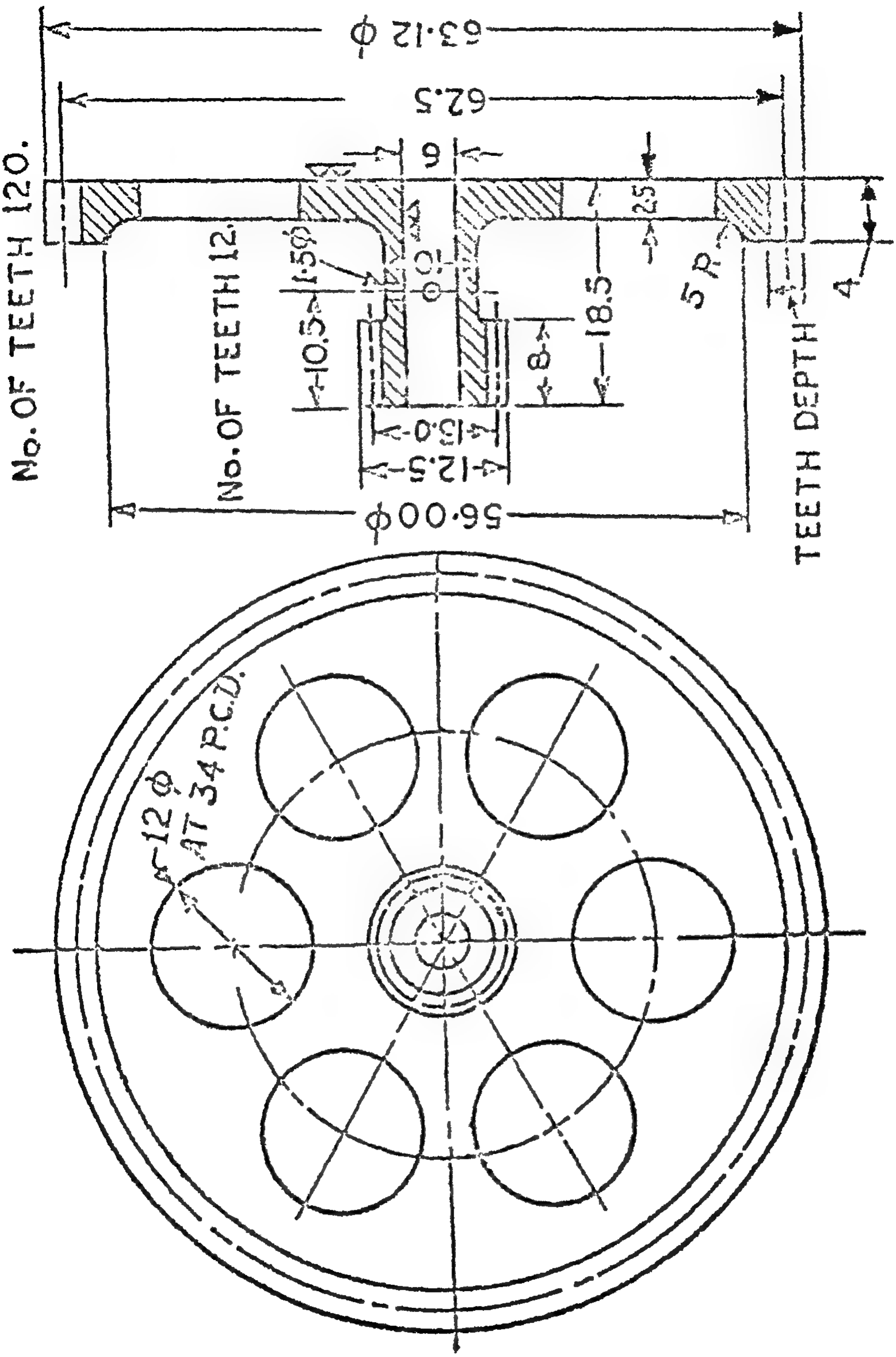
No. OF TEETH 120.
No. OF TEETH 12.
63·12 φ
62.5
6
2.5
1.5φ
10 φ
10.5
18.5
8
13.0
12.5
56·00 φ
5 R
4
TEETH DEPTH
12 φ
AT 34 P.C.D.

Fig. 26.4

CHAPTER 27

NEWER MACHINING METHODS

In the past two decades some new machining processes have been developed to shape the materials of constantly rising strength. These materials are widely used for supersonic planes, guided missiles and satellites and carbide tools and dies. Such materials are much more difficult to machine by conventional machining methods both from the point of view of tool life and surface finish. Complicated workpiece shapes and high tensile strength materials require new machining techniques. The thin sections required by engine designe must be produced without creating high residual stresses and distortion normally encountered in conventional machining. To meet this challenge of machining hard and high strength metals and alloys, such as carbides hardsteels and magnetic alloys, use of several forms of energies other than mechanical have been made for developing newer techniques.

13,00 Types of Newer Machining Methods :

Forms of energy	Methods
1. Thermal	Hot Machining
2. Electrical	Electro-Discharge Machining
3. Chemical	Chemical Milling
4. Electrochemical	Electrolytic Grinding
5. Radiation	Laser and Plasma Beam Machining.

13.01. Hot Machining :

Principle : The strength of metal decreases with increase in the temperature. Therefore, the magnitude of the cutting force on the tool should be lower than those which act on the tool while cutting metal at room temperature. It may also be derived out of it that rate of tool wear is less and the tool will remove a large amount of metal before its reconditioning becomes essential.

The development of hot machining method is due to investigators Schmidt and Armitage, Tour & Fletcher and Merchant and Krabacher. All these investigators have reported that less power is required to machine hot metals than metals at room temperature. This type of machining is not carried out with H.S.S. tool as the temperature encountered are sufficient to deform the cutting edge. Solid carbides tools are therefore, always preferred over H.S.S.

Methods of Heating :

(*a*) **Simple Heating :** Heat the metal in the furnace upto 900°—1100°C and then hold on machine tool with suitable fix tures

(*b*) **Flame Heating :** The workpiece is heated by means of a gas flame while it is mounted on the machine. This process is quite cumbersome and slow. Further, the work is also heated up beyond the cutting zone which is inefficient and undersirable.

(*c*) **Induction Heating :** This is a better way of heating the metal as it offers cleanliness and convenience. Cost of equipment and low efficiency are some of its limitations.

(*d*) **Arc Heating :** An arc is struck between the surface and carbon electrodes. This way of heating is quite convenient and reasonably efficient. It suffers from two drawbacks, *i.e.* non-uniform heating and surface damages.

In hot machining only that much heat is needed for the work which will not effect the properties of the workpiece.

Advantages :

1. Less power is required to machine hot metal than metal at room temperature, while machining with carbide tools.
2. Rate of tool wear is lower and hence tool life is always better.
3. Softening of metal due to heating provides cushioning to shock when the cutter enters the work.
4. No effect on the microstructure of the metal is observed.
5. No noticeable distortion of the workpiece is detected.

Field of Application :

Hot machining is employed for machining high strength, high-temperature-resistant materials which are difficult to machine at room temperature.

13.02. Ultra-sonic Machining :

Principle : This method make use of resonant electro-mechanical or magnetostrictive type transducer which generates linear vibrations at ultra-sonic frequency in range of 15-30 Kcs. The amplitude of the vibrations is very small *i.e.* 0.025 mm. These vibrations are transmitted to the tool through a mechanical focussing device (Fig. 27.01). The cutting process is purely abrasive in nature

and the tool used in the process simply performs hammering on the abrasive particles which are continuously circulated between the tool and the work (Fig. 27.01). Under the impact of the tool the abrasive

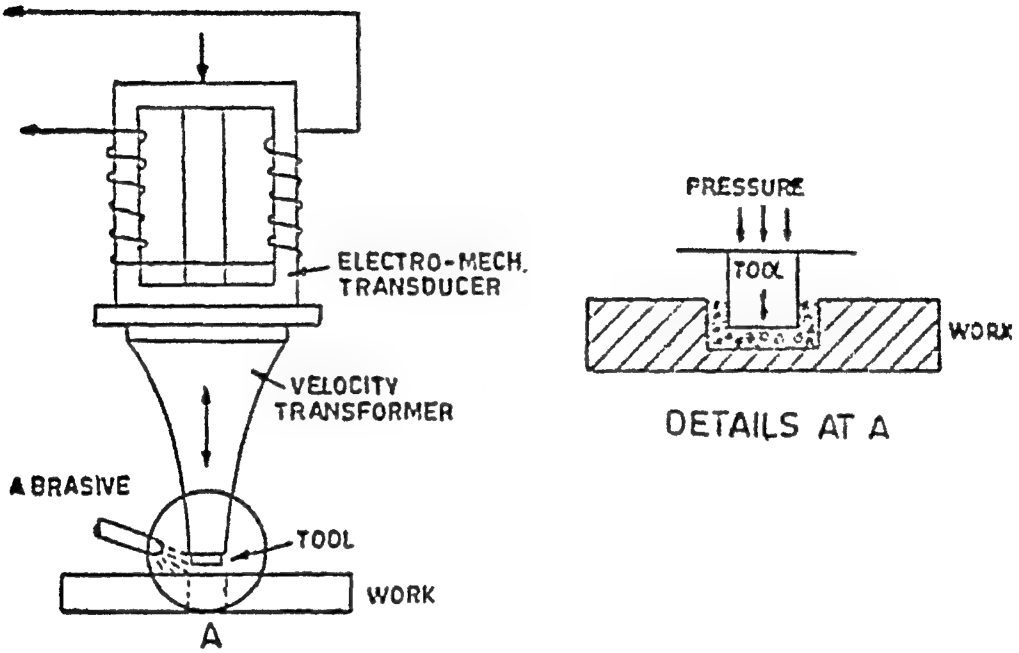

Fig. 27.01. Principle of Ultrasonic Machining

particles performs the metal removing operation, and thus the tool impresses its image into the work.

Tool :

The tool is made from tough material which does not chip easily but is capable of deforming plastically. Medium-tough malleable steel in cold rolled state is the best material for the tool, due to the reason (*i*) tool wear is small (*ii*) cutting rates are high and (*iii*) the tools can be manufactured rapidly and economically. The tools are also made of brass and copper. Tools with cross section areas from .02 mm to

80 mm can be used. Cuts as deep as 150 mm are practical in some cases. The tool moves in the direction of vibrations.

Abrasive :

The abrasive slurry contains fine particles of either aluminium oxide, boron carbide or silicon carbide, the grit size ranges from 180 to 800 mesh. Larger the grit size quicker is the cutting action. However, the finish is of low degree. Smaller the grit slower is the rate of cutting and better is the finish. The slurry is prepared in water and is kept recirculating until the cutting edges of the abrasive particles are dull.

Cutting Speed & Surface finish :

Ultra-sonic machining is best suited for hard and brittle materials. It is expected to remove smaller stock. Therefore, the materials are cut at very slow speeds. Glass and tool steels have been successfully cut at 2 cm/min. and 0.1 cm/min; respectively. Sintered carbides and tungsten have been machined at very low speeds 0.05 cm/min.

The quality of surface produced is basically governed by the size of the grits. In general the order of surface finish varies between 0.25 to 0.05 microns.

Applications :

The principle of ultra-sonic machining process has been applied to drilling, grinding, tre-panning, slicing and honing operations. It has found wide applications in

(*a*) Tool Room for Diemaking and Profilling ;
(*b*) Dentistry

(c) Jewellary, for shaping precious stones ;

(d) Special machining operations such as drilling curved holes and screw threads on brittle materials.

The materials that can be machined with this technique are tool steel-ceramics, sintered carbides, precious stones, germanium, tungsten, titanium, glass, ebony, carbon, graphite, plastics etc.

Advantages :

1. High accuracy and good surface finish are easier to obtain.
2. Equipment is very safe to operate.
3. No heat is generated during machining.
4. Abrasives used are cheap and production cost low.
5. Materials unmachinable by coventional methods can be shaped.

Limitations :

1. It cannot remove larger amount of material.
2. It cannot be applied to softer materials.

13.03. Electro-Chemical Machining :

Electro-Chemical machining is a new field of metal removal which has been developed on two well-known principles given by Faraday and Ohm. The metal removal is carried out by maintaining an electrolyte between the work (anode) and tool (cathode) in a very small gap of 0 025 cm. between the two. The metal removal is due to the ion-migration towards the tool. The deposition of ions on the tool is prevented by pumping a strong stream of electrolyte in the gap which flushes off the metallic ions from the cutting zone. This electrolyte may be an aqueous solution of a salt (KNO_3, $NaCl$, $NaNO_2$)

This type of machining process has shown great promise for the production of holes and profiled-cavities in electrically conducting materials, for honing and grinding processes. This process has found good application in industries associated with the manufacture of aircraft engine parts, turbine blades and grinding of carbide tools and dies. Parts may be produced from virtually any commercially available metal and alloy of any hardness.

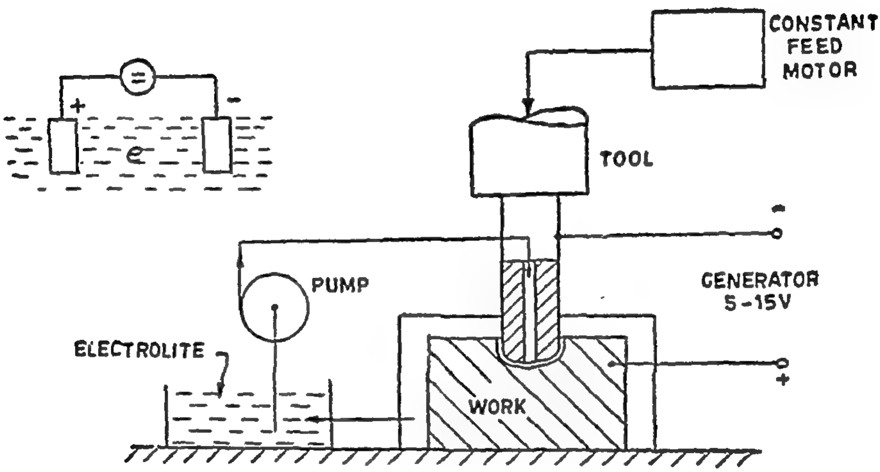

Fig. 27.02. Principle of Electro chemical Machining

Advantages :

1. The machining is done at low voltage.
2. No mechanical working is done on the surface.
3. Practically no tool wear is observed, as tool is not subjected to abrasion.
4. Machining capacity is independent of the strength of work materials and hence great variety of work material can be

machined. 15 Cu.cm material can be removed in one minute. Silicon steel which fractures during conventional machining can easily be formed.

5. Machining is carried at much below temperature (100°C) as continuously flowing electrolyte acts as a coolant also.

6. Dimensional finish can be controlled to 0.05 mm at average current density.

7. Possibility of burrs does not exist.

8. Extremely thin metal sheets can be easily worked without distortion.

Disadvantages :

The evolution of hydrogen gas in the process require provision for exhaust duct fitted with a fan. Production is low. Maximum metal thickness is 1·5 mm.

13.04. *Electrolytic Grinding :*

The principle of electro-chemical machining has been quite successfully applied to the precision grinding of hard metals since these metals, irrespective of their hardness, can be dissolved electro chemically. The grinding can be carried out on conventional grinding machine with some modifications to suit the process. The metal removal is both by electro-chemical decomposition and abrasion of the metal. About 90% metal is removed chemically and rest by abrasion.

The wheel employed on the machine is made of fine diamond particles in metal matrix. The particles are slightly projecting out from the surface, and they touch the work surface with very little

pressure. During grinding process, a continuous stream of non-corrosive salt solution (i0%KN^3) solution in water which acts as coolant and electrolyte, is maintained at the grinding zone. The

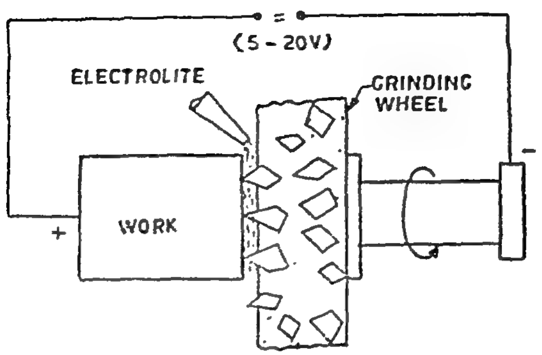

Fig. 27.03 Principle of Electrolytic Grinding

electrolyte is entrapped in small cavities between projecting diamond points forming electrolytic cells. When these cells come in contact with the work the current flows from the wheel to work and this lead to the electro-chemical decomposition of work. The short circuiting between the wheel and work is prevented due to point contact made by the fine diamond points. These protruding diamond particles also remove the unactive layers formed on the work by abrasion in order to meke the surface more receptive.

Advantages :

This method of grinding offers two advantages over the normal grinding method :

(a) Grinding pressure is very low resulting into stress and burrfree grinding.

(b) Heat effects such as grinding cracks, tempering of work and transformation of surface layers are eliminated. This

is because of the fact that electrolytic grinding is cold grinding process.

(e) Insignificant wheel wear guarantees cutter concentricity.

Applications :

Electrolytic grinding is mainly applied to resharpening of carbide tools and other materials that are difficult to grind. As the grinding pressure is low, it is possible to grind and cut thin sections such as stainless steel, cobalt, titanium cermets and thin wall tubing (injection syringe) without distortion or burr.

13.05. Electro-Discharge Machining (E.D.M.)

In electro-discharge machining the metal removal from the workpiece takes place due to erosion caused by rapidly recurring spark discharges between tool and work. The spark discharges are created by impressing sufficient potential between the tool and work separated by a dia-electric in between a very small gap. A cold emission of electrons starts from the cathode (TOOL) which impinges on the work surface (anode) and thus developing a very high temperature on the affected zone. This temperature is sufficient to melt and even vapourise a part of the metals. This leads into the removal of metal from the work.

The spark discharges are produced by using a relaxation circuit. In this case the direct current charges a condenser which discharges as soon as sufficient voltage (50V) has been built up across the condenser plate. The condenser discharging takes a very small time (30 sec). The rapid charging and discharging of condenser is

responsible for the production of low frequency high intensity spark in the tool work gap. One estimate has revealed that 1000 to 250,000 sparks go across a gap of 0.025 mm in one second.

The dielectric is used for the following reasons :

1. It breaks down under the influence of the applied voltage and hence helps in the movement of the sparks.
2. It controls the spark discharges.
3. It carries away the heat and therefore, acts as coolant.
4. It washes away the metal particles removed during the process.

Therefore, the dielectric should possess safe flash point and ow-viscosity. Kerosene is a very common type of liquid. Dielectric hrough gaseous dielectrics are also used in certain cases.

The tool is made from brass, cast iron, copper or copper ungsten alloy.

dvantages :

The process of electrodischarge machining offers several dvantages as listed below :

1. Hardness is never a limitation for the removal of material. It can machine hardest known materials.
2. Loss of metal in the machining is very small.
3. High degree of surface finish can be obtained.

4. The tool and work are never in contact with each other therefore, no cutting force acts upon the work. This enables the machining of thin sections without any distortion.

Disadvantages :

1. The rate of metal removal is very slow.

2. The process is not economical on softer materials for those operations which can be conveniently done by usual machining methods.

Applications :

1. For shaping carbide dies and punches having complicated profiles.
2. For making large number of small holes in sieves and fuel nozzles.
3. For making curved holes in the body.
4. For embossing and engraving on harder materials.

It has also been found economical to use EDM as final finishing operation after hardening as this will eliminate any distortion remaining in the body without affecting its hardness. In certain cases, other maching methods are used to remove a larger volume of material and then employing EDM for the final finishing.

13.06. Chemical Milling :

Chemical milling process was developed by American Aircraft Industries for preparing the parts having large curved surfaces and thin sections. Many difficulties were encountered in preparing such

surfaces by convention milling operations. An effective substitute for milling was developed from the chemical etching of the metals. This method of metal removal was given the name of Chemical Milling.

Chemical milling is carried out in four main steps :

1. Cleaning
2. Masking
3. Etching and
4. de-masking

The surfaces is thoroughly cleaned from dust and other deposit both by mechanical and chemical means. The whole surface is sprayed with Teoprhne Rubber or Vinyl plastics and then baked. The film of maskant is removed from the surface to be etched with the help of suitable templates. The part is then dipped in a tank containing an etchant (caustic soda for Aluminium, and acids for Steel and Titanium). After the required amount of metal, metal has been removed from the surface, the work is removed from the bath demasked and cleaned thoroughly.

Advantages :

1. Surfaces with complex profiles on thin sheets can be prepared.
2. Both sides of the work sheet can be prepared at a time.
3. No mechanical working is done on the surface which offers higher fatigue.
4. Process reduces tooling time considerably.

Disadvantages :

1. Larger work area is required because of the size and number of baths required in the process.
2. Cost of making is high.
3. Lower metal removal rate is available (·02 mm per min).

QUIZ

1. Enumerate the reasons responsible for the development of newer machining methods.
2. Classify the different machining methods on energy basis.
3. What is the most salient features of hot machining ?
4. Describe the principle of Ultra-sonic machining.
5. State some specific applications of Ultra-sonic machining.
6. How is EDM done ?
7. Explain the function of relaxation circuit in EDM.
8. Describe the principle of electro-chemical machining.
9. How does the metal removal take place in the electrolytic grinding bath, by abrasion and chemical decomposition ?
10. What is chemical milling ?

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